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NATURAL LANGUAGE INTERFACES TO DATABASE SYSTEMS

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Database management resulted from a need for data to be retained in the computer beyond the period of the current run. Since the earliest times of computer interaction, retrieving this data has been a significant problem. The motivation for this study was to look at the history of database in order to critique the human-computer interface with databases and to project the next areas of research in database management. A chronic consequence of man's normal condition of possessing incomplete knowledge of the detailed information to access and use that data is query failure. Although all query failure is frustrating, natural language failure can be especially insidious because it can fail by giving erroneous information to an unsuspecting user. Despite the current level of enthusiasm for natural language communication with the machine, this emulation of human-human communication may be the wrong approach to improving human-machine communication. A better approach may be to use methods of artificial intelligence such as semantic networks and object-oriented programming to create information sublanguages. Such a sublanguage would relieve the user of the need to have knowledge of database meta-data. Adaptive methods, flexible interaction, conceptual pattern matching and disamibiguation methods represent paradigms that can be employed into a new (i.e. beyond relational) hybrid database to strengthen the underlying structure of databases befor communication with them can be improved. This paper provides suggestions on research directions in order to achieve that strengthened database structure.

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NATURAL LANGUAGE INTERFACES TO DATABASE SYSTEMS

AN EVOLUTIONARY STEP TOWARD MORE EFFECTIVE HUMAN-DATABASE INTERACTION

Prepared for

U. S. ARMY INSTITUTE FOR RESEARCH IN MANAGEMENT INFORMATION, COMMUNICATIONS, AND COMPUTER SCIENCES (AIRMICS)

By

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EXECUTIVE SUMMARY

Database management resulted from a need for data to be retained in the machine beyond the current run. This need arose in the early prehistory of computers. Since these earliest times of computer interaction, humans have had difficulty retrieving data they stored so easily. The database eras have stretched from secondary storage on cards, tape, drum, and disk through physical databases to today's current technology of the fully relational database manager and logical databases in the form of relational views. The progress has been slow and not without difficulty. The motivation for this study was to look at the history of database in order to critique the human-computer interface with databases and to project the next areas of research in database management.

A human has limited ability to store the vast details about the entities of his world. He is usually dealing with partial information. He would like to move from his state of partial information to a state of more complete information. Computers with their enormous capacity to store vast detail are a natural extension of man's capability to use machines to assist him in this movement. But because the user begins with only partial information, he often finds it difficult to retrieve the information so easily stored at the time of initial data entry.

A chronic consequence of man's partial information in interacting with databases is query failure. Query failure occurs in various forms: structured database query failure, unstructured database query failure, and natural language query failure. All database query failure is frustrating, but natural language failure can be especially insidious because it can fail by giving erroneous information to the user and the user may be completely unaware of the failure. In fact, emulating human-human communication (i.e. natural language) may be the wrong approach in attempting to improve human-database communication. This is because human-human communication is based on far more than verbal cues; it includes all the human senses vision, smell, touch, taste and sound.

A better approach may be to use methods of artificial intelligence such as semantic networks and object-oriented programming to create an information sublanguage. This information sublanguage does not require the user to have knowledge of database meta-data. It has adaptive methods, flexible interaction, conceptual pattern matching and disambiguation methods. This paper shows how all of these methods must be combined into a new (i.e. beyond relational) hybrid database to strengthen the underlying structure of databases before communication with them can be improved. This paper suggests research in three directions in order to achieve the strengthened database structure: (1) building on existing foundations, relational databases; (2) building new foundations, value based semantic networks; and (3) a new interface paradigm, visual/graphic thesauri.

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AN EVOLUTIONARY STEP TOWARD MORE EFFECTIVE HUMAN-DATABASE INTERACTION

1. INTRODUCTION

Natural language comprehension has proven to be an enormously complex task. It is still far off as a day-to-day tool for effective human-database interaction. The need for a more human style of human-computer communication will not wait for some distant future development. Although interactive query and command languages have proven vastly superior to batch oriented, procedural programming languages in terms of programmer productivity, the barrier between man and his information stores remains largely unscathed.

What is needed is an incremental step, an evolutionary development to fill the chasm between the existing query languages of today and the natural, human communication with computers promised for a distant tomorrow. This step would properly be filled with a cooperative, flexible, and more expressive hybrid of Data Sublanguages (such as SQL), Object-Oriented encapsulation from programming languages. semantic networks from artificial intelligence, and visual/graphical interface from man-machine studies. Where data sublanguages require precise syntax and exact matches to both the structure and content of the information store, a hybrid sublanguage would be more forgiving and helpful. The data sublanguage user must think in terms of logical data structures while a hybrid sublanguage user thinks in terms of the objects and concepts of their domain of interest. The hybrid sublanguage is the means for an information systems user to effectively and efficiently navigate and cultivate a dynamic information terrain with which he is not entirely familiar. It is not intended to convince a user that he is conversing with a computer-based agent that understands the world in a human fashion.

The report begins with a look into the history and context of these proposed developments by analyzing the evolution of database through the current era. Then the problems that plague human - database interaction are analyzed and potential solutions with their limitations are considered. Lastly, a framework of research and development is sketched out to move into the next era of database.

The study is flavored with several methodological principles:

- examination of technologies and research traditionally inside the database area,
- examination of technologies and research traditionally outside the database area,
- recognition that human-database interaction runs deeper that the human-computer interface and critically involves data representation and database design methodologies, and
- avoidance of a single focused orientation (e.g., domain oriented, user centered, machine based).

Today's databases are the product of decades of evolution. New developments must form a natural extension of this progression if they are to be easily incorporated into mainstream computing. This report is addressed to those groups and individuals having any of the following goals/agendas/responsibilities:

- transforming current databases with the next generation of technology,
- solving access problems with existing databases,
- developing database applications over the next decade,
- developing database management systems,
- planning systems with a mission critical database component, and
- conducting research in the database field.

2. HISTORICAL CONTEXT

Evolution of Database

The evolution of database can be illustrated with a time line from prehistory through the future. Prehistory is essentially the 1920's, 30's and 40's - out of which computer science as a study and a professional discipline arose. Database is a research area that emerged from the prehistory along with artificial intelligence, programming languages, software engineering, and other research areas of computer science.[1]

As shown in Figure 1, the various eras on the database historical time line are: secondary storage era, physical database era, logical database era (relational database era), and the future.

Most people, whether they are from the research community, academia, the corporate world, or the press, think that the future of human interaction with database should mimic the way we interact with each other as humans. And that generally means understanding spoken and written communications in a "natural language interface." If a human wants to know something from a database, he simply asks it like he would another human (in natural language, whether typing or talking) and the database will respond with the requested information. This study will examine this premise and show why it is unlikely to ever be achieved, at least under the current state of database theory.

During prehistory, database and computer science were in their infancy. Computers filled large rooms and were made of vacuum tubes, not semiconductors. But the most interesting aspects of prehistory were the users. Computers, as archaic as they were, were considered to be very friendly by the users, even though programming was generally in binary.

The difference though, compared to today, is that typical users back then were John Von Neumann, father of quantum mechanics; Claude Shannon, father of information theory; and Norbert Weiner, father of cybernetics. Typical users were highly educated people, often Nobel laureates, and they had no problems interfacing with their devices. Plus the fact that the tasks they were using the machines for were fairly low level and straight forward. They were not trying to find out sophisticated conclusions from an accounting system, but rather just trying to find the results of a specific equation evaluated over a certain numerical range.

Out of this prehistory (see Figure 1), it was determined at some point that there was a need for reference to data beyond that which was stored in memory of the computer. As data sets grew in size, a need developed for storing data when the power was off to avoid re-entering data for each run of the calculations. External physical devices were developed such as punched tape and Hollerith cards, magnetic tape and, eventually the most important device to the user in database, physical disk drives in which data could be accessed randomly. The tremendous advantage of the disk drive was that the database did not have to be read sequentially from the top to find the required data, rewound and the cycle repeated as in other devices (e.g. tape storage.) That was the beginning of the first real era of database, the era of secondary storage, where secondary storage is defined as anything from punched cards to on-line, random access devices. This point is chosen as the beginning of database because it was the first time functional users began to gain access to data generally throughout the organization.

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1 Superscript numbers refer to the list of references in 10. REFERENCES.

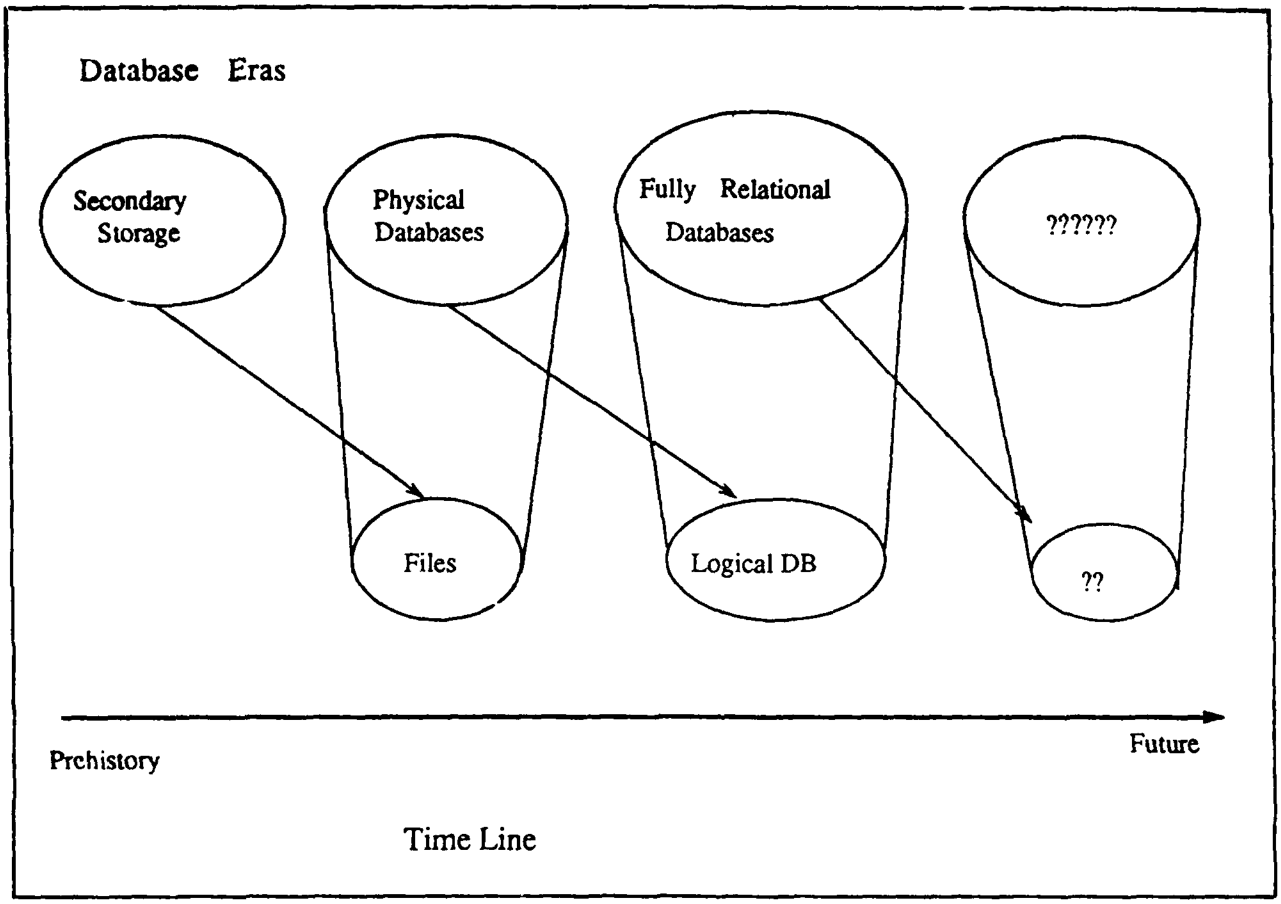

Figure 1 - Database Evolution

The problem with pure secondary storage devices was if the user wanted to access data on the physical storage device he needed to know exactly where it was located on the physical device. He had to refer to its physical location: what track it was on, what sector, how many inches from the beginning if it was on a magnetic tape, or where it was in a stack of punched cards.

The next stage in the development of database grew out of the strong desire to refer to data independent of the location on a physical device. And it turns out the secondary storage era sowed the seeds of its own destruction because someone said, "Why must we address a physical device, why can't we have a file that is logical? Rather than knowing where our data is, why can't we just name the collection of data we desire and let some software find it physically and bring it back to us?" The era of secondary storage gave birth to something new: the concept of a file.

A file is a collection of data whose physical location on secondary storage is transparent to the user. The physical location, retrieval, and other operations on the collection of data are managed by software written especially for this purpose and which is tightly coupled to the disk and computer hardware. As an example, a text file may be relocated from the outside tracks of a fixed disk drive to the inside tracks by a backup and restore procedure. Indeed at certain times in the history of a file it may not all be physically located in adjacent storage areas. The physical location of a file has no effect when a word processor is instructed to load the file into memory so that it can be edited.

Although the file concept makes physical location of the file on secondary storage transparent, locality of the data within the file remains as a problem to the user. That is, the data collected within the file is structured to some extent (the minimal structuring is sequential, one data item followed by another). The need to know where data resides on a physical device is replaced by the need to know its logical position within the file. Physical navigation is replaced by logical navigation. To find the data sought may require positioning a pointer at the logical beginning of the file and sequentially navigating through it until the desired data are encountered.

The amount of structure of a file varies across a continuum - from a simple sequence of characters as in the most basic text file (relatively unstructured) to the opposite extreme, as in a file of identically structured records, each record consisting of predefined fields of data, some numeric, some alpha, others binary (highly structured). Figure 2 below conveys this general difference.[2]

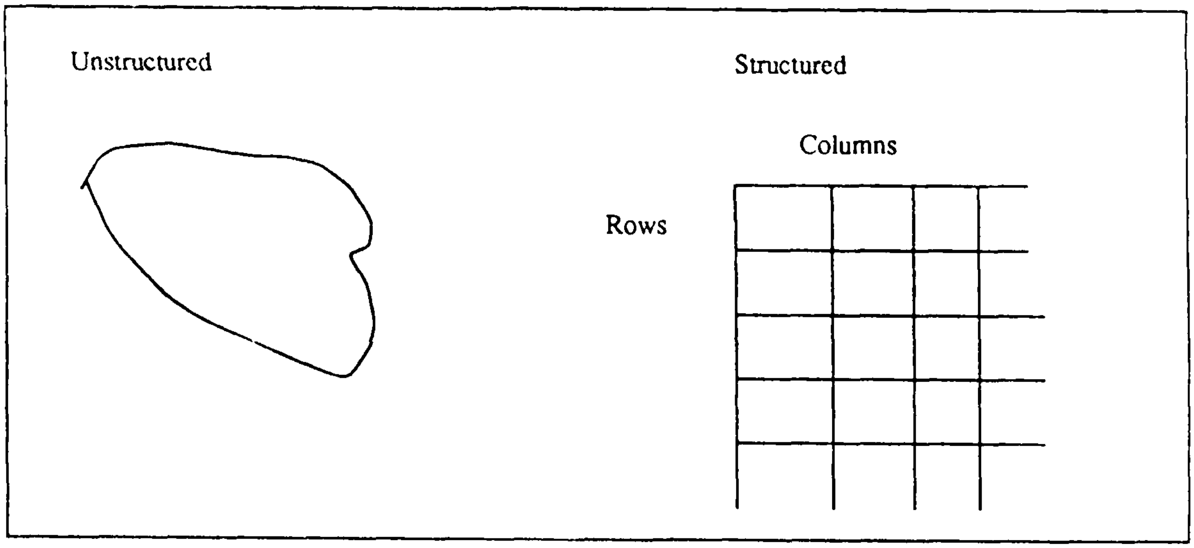

Figure 2 - Unstructured vs. Structured Database

The polygon on the left is not the blob, even though it has been known to eat up large sums of money, time and patience. It represents an unstructured database. On the right is a structured database, depicted by a table of records and fields. That is the contrast between structured and unstructured file storage. Structured files are files where the meta-data of the data model must be predefined and the data filtered into it. Unstructured files have a mass of text or numbers or statistics and it must be navigated with little or no guidance. Sometimes unstructured files are a lot richer.[3]

An example of this is a literature collection containing articles of professional interest. This collection is an extremely rich source of information; but one pays the price for having richness in the ability to search the database and retrieve desired information. Because both storage and retrieval of the information rely on the structure of English and the knowledge humans have in their brains when they read it, finding requested information is difficult and slow. The database needs a human being to understand it.

On the other hand , structured data have been filtered and parsed into various meaningful units, fields. The structure is so finely broken up it has only limited meaning and this meaning is well defined. Precisely because structured data has been designed with limited meaning, machine manipulation and interpretation are feasible.[4]

As the file concept matured, files were grouped together and put into an organizational structure. So files grew up, so to speak, and matured into the concept of a physical database containing several related files linked together.[5] As an example, take a file of departments and a file of employees. These two files might be put into a hierarchical database with pointers from one file to the other. The file for department has information such as the department number, the department name, and an employee number for the person who is the manager. It would also have pointers to records of information in the employees file. Each of these records would be identically structured with an employee number, a last name, first name, address, etc. Access to all of those individual employees cannot be gained directly through the employees file. The department file must first be traversed to locate a department, then follow its pointers down to find out what employees were there. In other words, an employee could not be accessed directly, but only through his department. The physical access path had to be followed. The paths were physical because, although the pointers were unseen, they were located in one file and pointing to locations in other files. It was necessary to navigate both between files and within files to locate data. Simple requests for data required lengthy programs for retrieval of the data.

Physical databases had offspring too. Physical databases gave rise to the notion of a logical database. The motivation for logical databases was to gain access to data without explicitly following the physical path. In the context of the employee example, why can't the employee data be accessed without passing through the departments file? Ted Codd, father of the relational database model, developed the notion of a logical database and developed the theory of logical databases on a rigorous mathematical foundation. In a relational database, software handles the access paths and navigation, almost transparently to the user, but problems still exist. For example, the user must have knowledge of the structure definition of the database (the meta-data) in order to effectively use the database.[6]

Logical database is maturing too. In 1988, fully relational databases are appearing in the marketplace. As logical database is maturing, the question is, "What kind of offspring is it going to give rise to?" Actually, that's a question of "What do we want it to give rise to?" So, there are some question marks. What's going to be the new infant? What's it going to mature into when it gets a little older? In the sections that follow, these questions will be addressed and a radically new database model will be proposed that allows for innovative human-database interaction.

Evolution of Usability

This evolution, if examined, has not really given rise to more powerful or faster tools. Today, operations with the latest fifth generation database management system are not going to be any faster than if the old software was running on the latest hardware. Performance will not be significantly less than the latest fifth generation software. In fact, because the old generation software was finely tuned to the application by clever programmers, more performance is likely. So the evolution of database does not represent an evolution of greater power or speed. The fascinating aspect is that it represents an evolution of usability and more effective user interaction.[7]

In the secondary storage era, databases were addressed at a very low level and it took someone like a Nobel laureate, or someone very intelligent and very capable, to do it (over long periods of time). Moving to the era of files and physical databases, it became much easier. Programmers could access data. They did require training and had to be expert at what they were doing. But they didn't have to be a Nobel laureate.

And now as logical database/relational era evolves, people claim that anybody can access data. Of course, that's not quite true yet. Limited natural language interfaces - Natural Language Interface, Intellect, Clout - help but they have serious inherent deficiencies. They are making it easier and further removed from the physical databases underlie it all. It is important to note that this evolution of database is really the evolution of human computer interaction to provide better and more effective interaction, not speed and power from a software standpoint.[8]

Evolution of Non-Database Areas

As noted previously, prehistory spawned many areas of computer science research. Examples include: artificial intelligence, software engineering, programming languages, and many more. In early database development, these disciplines had no impact on the database evolution. These disciplines are now impacting database development as computer science it self emerges as a mature discipline. In addition there are other scientific disciplines outside computer science which are impacting database design. These include design, development, and management methodologies from the engineering world, theories from cognitive science, and requirements from application areas (e.g. iterative design methods.)[9]

Programming languages followed a similar and converging evolution. They started at the physical level where the user physically programmed individual logic circuits. They moved up to the level of assembly language where machine instructions were addressed in a specific but still very low level programming language. They then moved up to third generation programming languages such as "C", Basic, Fortran and Cobol, where the programmer dealt with a logical machine, not the real machine, making programs more easily understood. Now, database and programming languages are merging into fourth and fifth generation languages which are even further removed from the machine. That course is: let's get further and further from the real hardware and let us interact instead with a virtual machine. Although database has evolved in near isolation from the other disciplines, continued evolution should be far more integrated with the rest of the world.

3. THE DATABASE PROBLEM

Query Failure

It's important to consider the purpose of databases and why humans want to interact with them. They know something the human doesn't know, or he once knew and forgot. Humans have limited ability to store vast specific detail about entities of his world. Therefore he is almost always working with partial information. He would like to get from a state of having partial information to having full information. But because he has only partial information it's not easy to pinpoint where the information is and how to get to it. This is the problem. Before something can be found, it must already be known. A chronic consequence of the problem is query failure. Three examples of query failure will be examined: structured data, unstructured data, and natural language access methods.[10]

Structured database query failure

Looking first at a structured query example using an employees table and structured query language (SQL). The database has an employees table with columns as shown in Figure 3:

EMPLOYEES					
Emp_Num	Salary	Age	Department_Num	Last_Name	First_Name

Figure 3 - Employees Table

Assume the user wants to find all the employees aged 25 years or younger in Department 2 that earn more than $35,000 a year. Write the query as shown below: (No particular database language is used)

```
SQL>    Select Emp_Num, Last_Name from employees
        where salary > 35000
        and age < = 25
        and Department_Num = 2;
```

What if the system responds as follows:

```
0 rows selected
SQL>
```

What does that mean? Well, obviously it means there are no employees in Department 2 whose salaries are greater than $35,000 and 25 years old or younger. But the real question is how to interpret the negative response. Does it mean that no one less than 25 years of age has been able to be promoted rapidly enough in order to earn more than $35,000? A second query is formulated by revising the age limitation upward and leaving the rest of the query alone. This is a standard strategy in solving query failure: change one element of the query and see what happens. The second version of the query is:

SQL> ....age < 30 years old

Once again a negative response is obtained:

0 records selected
SQL>

Try reducing the salary limitation:

SQL> ...salary > 30000 and age < 30

Yet again:

0 records selected
SQL>

Variations of the query could be continued until exhaustion of the user. He eventually may give up. Or, he may finally discover there is no Department 2. He could have queried on Department 2 forever and never found a positive response. Or he might find that Department 2 was Sales and all employees there are on strict commission. They don't earn a salary. Unfortunately the problem would not be identified by the database for the user. This query, as so many queries, has failed.

In the case above, if the user is a naive user and doesn't know too much about the company and the data, he will have to do a lot of work to overcome the query failure - even with just one table of data, not hundreds or thousands of tables. To move between a state of ignorance to some state of knowledge, from having partial information to complete information additional information is required (e.g. knowledge of meta-data.) Query failure happens because the database system has not helped you in progressing from partial information to complete information.

The database is not acting in a cooperative or adaptive manner. It insists the user know in advance the information he wants to find and the manner in which the database knows it. Only then can a user ask the database for data and obtain positive results right away. That defeats the purpose of the database and places barriers between many users and their data. Even in the era of the fully relational database, which is just dawning even now, query failure is a significant problem.

Unstructured database query failure

Medline is a very large unstructured database which has medical information for doctors. This is a very large database and browsing is virtually impossible. It would be as easy to walk around a large university library browsing to find the book you want if the books were all in a heap on the floor. Not very helpful.

A study was done in which queries were issued to the Medline system. A doctor, untrained in Medline, and a librarian, trained in the on-line information system for Medline, were utilized in the study. The doctor told the librarian what he wanted, the librarian formulated queries to the system.

In querying the system, only 20% of what was actually in the database and relevant to the query was returned. In addition, 20% of the responses were not on target with the query. The result is four times as much information remains in the database as was returned. Given that only 80% of the return was useful, only 16% of the useful information was found. That's another instance of query failure."

Now you can ask why does it happen? Well, first you do not have a human being browsing the entire database, reading each journal to answer a particular query. The database had to be indexed in some fashion. Perhaps through keywords or abstracts. The people who made those abstracts or defined those keywords did not have this particular doctor's query in mind. And perhaps additional knowledge came to light after the journals and periodicals were indexed. And as a result, the system only found a small fraction of the information that was available. Is this important? The reason for the existence of databases is to answer queries. If they can't do it they are not serving their purpose so it certainly is significant and important.

Natural language query failure

Can natural language help here? The authors attended a demonstration of a recent natural language product currently being sold as a front end to the Ingress database manager. The name of the product was Natural Language Interface (NLI.) A database in Ingres that had employees, employee numbers, their salaries and some other information in a table was used in the demonstration. A query was issued in natural language using NLI. The query was:

"What is the average salary for employees in the shipping department?"

The response to the query was:

"Average Salary = $25,000".

But several questions immediately come to mind when an average salary is computed (not to mention the harassment of typing a lengthy query.) For example: what was the denominator one divided by to get the average? That is, how many employees were used to compute the average? What was the range of the salaries used in the computation? Was it one very small salary and one very large salary which gives a totally meaningless average? Or was it 35 different individuals with salaries very closely clustered together? Different interpretations of the average salary are inferred based on the dispersion and the number of the salaries used for computation.

When the queries suggested above were made into the database, multiple and different responses were returned. Ultimately, it was discovered that the average given in the original response was not even correct! The query failed because of ambiguity. There was no indication of a problem when the original response was given. The user had no indication the query had failed but he had been given incorrect information. This is an example of an extremely dangerous and insidious form of query failure. Instead of the database saying it's unable to answer, it answers with erroneous information. And the user was given no indication of a problem with the query!

The queries continued into this same database. The example question:

NLI> "Is Jeremy rich?"

The system responded,

NLI> "Jeremy is rich."

But next, the query was made with "rich" having the double meaning of the name of an entity and the concept of wealth. How does one interpret this inside the database context? As a rule, natural language systems can not assign multiple meanings to the same term. And, therefore, the query:

NLI> "Is Rich rich?"

failed. NLI couldn't handle the multiple meanings inherent in homonyms (words that sound alike but have different meanings) even though the database did have information on salary for all the employees, including Rich. The system would not allow assignment of a wealth meaning to "rich" (salary greater than $50,000 a year) and simultaneously the meaning of an entity contained in the database (the individual named Rich). This was a significant problem with NLI and the system gave no help at all when it failed.[12]

Adaptive methods

What technologies, methods, philosophies, etc. are available for addressing these database problems? What is needed is an adaptive component in the database. Adaptive in that it can take what the user knows about the database, its structure and content and match to what the database knows and return the best possible answers. There are a number of adaptive methods available and these are discussed in the following paragraphs.[13]

Pattern matching

At the lowest level is character pattern matching. One possible source of query failure occurs when a typographical error occurs in the query. The database query parser doesn't understand the query. If there is a character pattern matching component in the database query parser it could give provide possible alternatives. For example, suppose a query into a database of cars is:

I am looking for a porsh.

The database should respond with:

I don't understand porsh. Do you mean a Porshe?

If it can't do that, it's not helping the user get from his state of partial information to a state of more complete information. Spelling checkers are generally available today and adaptive pattern matching algorithms exist which can be used to give spelling support. Paradox from Ansa Software, for example, provides some of this kind of assistance.

Disambiguation

A step up the adaptive methods ladder from character pattern matching is disambiguation. Reconsider the query

Is Rich rich?

The system must disambiguate the double meaning of "rich" in the query. The first use is as the name of an employee in the context of the employees table and the second is a question about the wealth of the employee Rich. This is much more complex effort because not only does the program code need to disambiguate the meaning of the terms, it must have information and knowledge about what they could mean in different contexts. This implies the existence of a sophisticated thesaurus and algorithms to do the disambiguation.

What does this mean for a database? In order to get adaptive interactions that include disambiguation, the structure of the database needs to be sufficiently strong so that one term can have many meanings. And it must have many meanings in a form that the database itself can use to resolve the ambiguity. In other words, in order to get an interaction with the database to be more friendly and effective the underlying structure of the database needs redesign. The existing database design model is not sufficiently robust to simply put a front end processor on it and obtain the desired results.[14]

A lot of marketing people and researchers want you to think that you can take an intelligent interface and throw it on top of a stupid database and have an effective interaction. But effective interaction isn't just intelligent interface. It needs a foundation down underneath to support it. The failure of the NLI query cited above illustrates that in order to disambiguate the system needs a sufficiently strong foundation in the database to express multiple meanings for terms so the database can do the disambiguation.

Another new product on the market is Lotus Agenda. Lotus Agenda lies somewhere between structured and unstructured in that the user doesn't have to predefine a structure, but Agenda internally creates something akin to fields and records. It does pattern matching to the extent that if the user is doing something for Sue it will match on the word Sue and pull up everything it knows about Sue. It does not do disambiguation. If there are two people named Sue in the database, the last name is required or the query will fail. Or, worse yet, don't ask to sue your insurance company![15]

Relativism

The next area of adaptivity is relativism, a more abstract form of disambiguation. More abstract in that the multiple meanings are related. An example of relativism is the term marriage. From different perspectives the meaning is different. Consider marriage from the point of view of the catering company. To them a marriage is an event they have to schedule. In the eyes of the government, it's a legal entity requiring a license and an entry in the database of vital statistics. And lastly consider a marriage in the eyes of the husband and wife who consider it a relationship. So marriage is an event, an entity, and a relationship depending on perspective.

Relativism, like homonyms, must be disambiguated. Relational database and extended relational database such as Codd's Relational Model Tasmania (RM/T) cannot deal with this problem. Only the most advanced artificial intelligence formalisms such as semantic networks can represent something like this. To overcome the database problem where relativism is involved requires a representational formalism that is very robust. Current database models simply do not have the foundation to disambiguate relativism.

Presuppositional analysis

Presuppositional analysis was created by a number of people at about the same time in the late 70s. It's ironic that one of those people later happened to be the head of Research and Development for Lotus Corporation while they were developing Agenda and yet Agenda has no presuppositional analysis in it.[16]

Presuppositional analysis asks "If you say something or ask a question what does that question presuppose?". For example, if the question

> Which employees in the company less than 25 years old earn more than $35,000 and are in department 2?

Almost unconsciously, the user pre supposes a number of things by this query:

> there is a Department 2,
> the company has employees,
> the employees in Department 2 have earnings, and
> the employees have ages.

The thrust of presuppositional analysis is when a query fails, arrange the presuppositions into a hierarchy. The query is a massive, complex presupposition which can be decomposed into components. For example, employees with salaries in Department 2 pre supposes the existence of a Department 2, the existence of employees and the concept of salary (or possibly commissions.) The existence of Department 2 pre-supposes the existence of a company. In this way a hierarchy is created with each stage less and less specific.

If the system can use presuppositional analysis it can determine presuppositions and when a query fails it can start going down the hierarchy to find the presupposition that failed. Recalling the query failure in the employee example given above, presuppositional analysis would determine the faulty presupposition of the existence of a Department 2. The system could then inform the user of the problem with the query and even explain why it failed.

A feature of presuppositional analysis in its basic form is that it requires no special foundation underneath the front-end. It has been implemented on top of semi-relational databases. This feature is achieved by placing tremendous demands on hardware processing power while making minimal use of the underlying database structure. Presuppositions are identified and hierarchically ordered syntactically. By parsing a query by syntax, presuppositional analysis aims to roughly identify what's wrong with the user's query; it does not address the more positive problem of assisting the user in formulating a new and correct query. This is not the ideal way of helping a user traverse the distance between partial information and complete information.

Conceptual pattern processing

A step beyond presuppositional analysis is proposed by the authors: conceptual pattern processing. Conceptual pattern processing does not seek to inform the user of errors wrong in his query like pre suppositional analysis but rather it assumes the user is asking for valid data. Conceptual pattern processing therefore uses information in the database to discover data that best meets the requested data. In other words, it looks at the syntax of the query, the structure of the database and the semantic content of the query simultaneously to determine suggested lines of future queries.[17]

Rather than only looking for the syntactic component of a query that fails, a subregion of the database that comes closest to answering your query is sought. How is closeness measured? By examining the meaning of the terms in the query - the concepts the terms refer to given the overall context. Thus the analysis looks at conceptual closeness.[18]

The result of conceptual pattern processing may not be able to derive a single closest solution. There might be many and it would show all of them and allow the user examine the trade offs. He would know his options. Conceptual pattern processing takes an optimistic attitude rather than a pessimistic attitude toward query failure telling the user about success rather than failure. For example, extending the earlier example of structured query failure and considering the case where Department Number = 2 exists and is sales (with sales people earning commission only), the system, enhanced with conceptual pattern processing might respond:

There are no records which meet your request exactly. You may now -

(1) Cancel your query
(2) Edit your query
(3) Let me examine the database and identify rows that are closest to meeting your request.

If you now choose (3) and continue the system might respond as:

I have identified 2 distinct groups of rows from employees that are closest to meeting your request. Their descriptions follow.

Choose the group you would like returned.

```
(1)   Select Emp_Num, Last_Name
      from Employees
      where Salary > 35000
      and Age< = 25
      and Department_Num < > 2;

(2)   Select Emp_Num, Last_Name
      from Sales_People, Employees
      where Sales_People.Emp_Num =
       Employees.Emp_Num
      and Sales_People.Commission > 35000
      and Age< = 25
      and Department_Num = 2;
```

the user doesn't know what trade offs he is willing to make until he knows what trade offs are available. And therefore it doesn't require prioritization of the query to make one attribute more important than another. Conceptual pattern processing lets the user know what the choices are.

Currently, conceptual pattern processing requires a large amount of intelligence in the system. Humans must tediously enter that intelligence into the system; however, it does lead to more effective interaction as demonstrated by the prototype system Proto Atlas. Future developments in neural network systems that support self organization by the system should simplify this knowledge acquisition problem and support faster measurements of conceptual closeness.

<u>Flexibility</u>

Another problem at the interaction level is the problem of flexibility versus inflexibility. Database systems require that you specify references to things you want the way they want you to. And generally that's textual by a certain data type. In the employee example given above, if the user wants a certain employee's name he may enter their number. This number must be specified exactly. If it is specified with extra blanks or hyphens the system is not going acknowledge the query properly. In fact, the query probably won't make it all the way to query failure. It won't even be processed as a query because of parser failure. Beyond this the user must tell the database something about the data he is requesting in the query. For example, he can't just say:

> Tell me everything about John Doe.

Rather, he must specify the fields requested:

> "Tell me the salary and age of the employee in the employee table whose first name is 'John' and whose last name is 'Doe'".

The user must know the structure of the database. He can get to everything but he has to know the names of the columns and he has to specify the data correctly, enclose it in quote marks (Single quotes not double quotes), spelled correctly.... It's not flexible. Additionally, he can't say:

> Show me someone like John Doe but who's a little bit older.

The system requires very formal communication. The user also has to make proper references by direct identifiers that the system already understands and has been programmed to understand. He cannot use analogies, metaphors, or descriptions. On a more difficult plain, he can't simply point to a physical object and request the system to tell him everything about that object. He can't use any visual or other sensorial references because the system is primarily inflexible. How can the problem of flexibility be attacked? It requires underlying changes to the structure of the database. It requires a form that is as expressive as the world is varied.[19]

<u>Adaptive methods summary</u>

Simple character pattern recognition to address spelling errors and basic pre suppositional analysis are the only processes giving adaptive and flexible behavior to a database system that do not require substantial changes to the underlying structure of the database. Disambiguation, relativism and conceptual pattern processing all require structural changes. Addressing the problem of flexibility also requires substantive changes in the structural design of databases. The result is when it comes to making databases more adaptive and flexible and to making significant strides in effective human-database interaction, looking only at the interface is insufficient. There will have to be significant changes to the underlying structure of the database itself.[20]

You can train a monkey to be real polite but he's not going to be very informative. You haven't changed anything by teaching him a friendly grin. He can't tell you anymore than he knows. And that's the problem with the attitude that "We can dump an intelligent interface on top of data that doesn't have very much knowledge".[21]

4. DATA DICHOTOMIES

The data:meta-data and the data-use:data-design dichotomies are major limitations of current database technology for developing effective user interaction interfaces. These limitations are a direct result of the fact that data models are representations of data. The data are representations of the physical world. Therefore one is modeling a model rather than modeling the real entity. The relational model is the relational model of data. The user is utilizing sophisticated query tools but is interacting with simple, primitive data. The same data that's on the physical devices. The user just has a more elegant, higher level interface to it. They are not dealing with a high level of the world, they are not dealing with concepts.[22]

The database designer had to come into the company, look around, use his mental faculties and say, "There are employees. There are departments. There are relationships." He did the conceptualization. And as a second step he figured out the entity types that were necessary to organize the data for automation. This process is named data modeling. There are people who have a high level of expertise in data modeling, which includes designing schemas. This is not a trivial task.[23]

Roots of Data:Meta-Data Dichotomy

The difference between the structured and unstructured databases is quite important. A good example of the structured is corporate management information systems. An unstructured example is ISARS, Information Storage and Retrieval Systems. A good example of an ISAR is the library. You are storing documents, you want to retrieve documents. That is your primary task. That is what you are interested in doing. How do you do that?

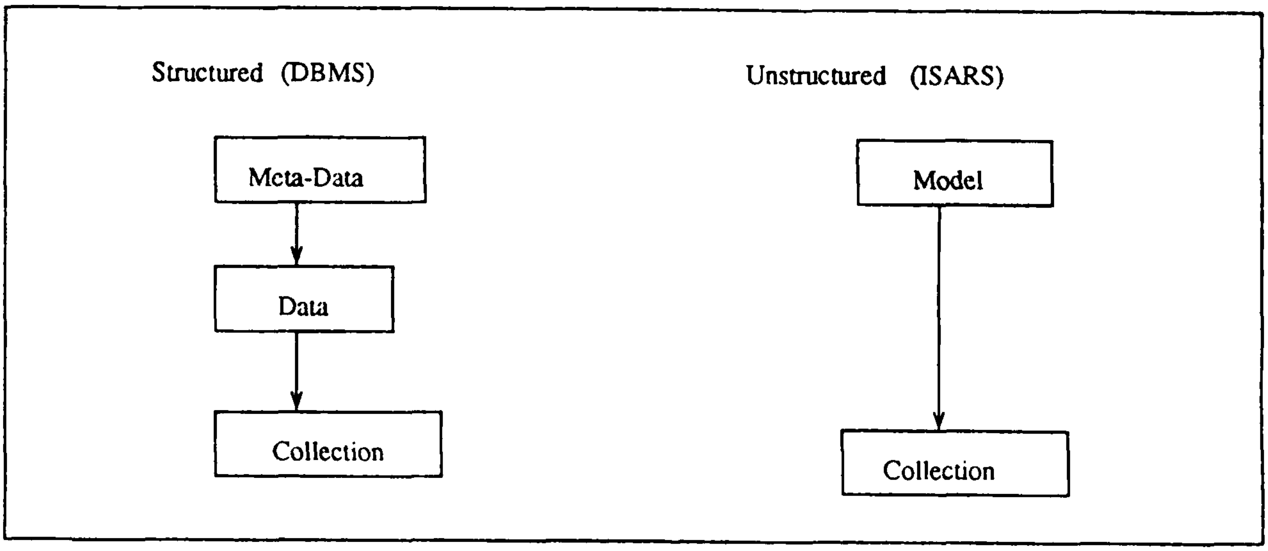

Figure 4 - World Modeling vs. Data Modeling

ISARS is a collection of documents, books, journals, etc. Eventually, the collection gets too big and overwhelming to deal with directly. Simplification becomes necessary. We need to deal with something similar but not as hard to deal with. A model of the collection is created and the model is in a form that is much easier to deal with. Instead of a big heavy book, there is a small synopsis on an index card. So in a simple case, the model of the collection of documents might be a card catalog. If you want to find a book you look through the model. You manipulate the model. You do a query on the model rather than going through the entire collection of books. You find a reference to what you want and then you go back to the collection of books and check out the real one.

Modeling is a representation that compresses space and/or time. In the card catalog a large library spread out over a large space is collapsed and made nonlinear. One can browse through books by browsing the card catalog. You can go from one document on one side of the library to another document on the other side by going from one card to the next.[24]

The truer the model is to the collection, the more you can do in the model and the less you have to do in the collection. If the model doesn't give good descriptions of the books, you are going to have to keep going back to the real library and read through real books and then go back to the model with additional constraints.

But what happened in the structured database management world? Originally there was a collection: employees, departments, customers. But that is not what got modeled because the company started collecting data on its employees, departments and customers. The data started getting out of hand and became very difficult to deal with. Whether it was in file cabinets, manuals, old style spread sheets on paper, or ledger books.

Next came management information systems and database management which created a data model. The data model is not just one step removed (as was the information storage and retrieval system) from the collection, but two steps removed. The data was a representation for the real thing, the employees, departments and customers. The data model was a model of the data, not of the domain. The model of the data is called meta data.

On one hand, information storage and retrieval systems did something good. It didn't introduce meta data. It didn't introduce data into the system then start modeling it. It modeled the real thing. On the other hand, it did something bad. It hasn't progressed very far. It's really still stuck back in the physical database era. It hasn't progressed into the logical state yet. It's still lagging behind. Database management systems, on the other hand, did introduce this extra layer of meta data and as a result, more highly evolved technology of logical database systems was needed.[25]

Problem of Data:Meta-Data Dichotomy

The data:meta-data dichotomy is the distinction between the values in the database and the structure of the database. Values in the database change often. The database management system makes it easy to effect the changes. In contrast, meta-data are very difficult to change. Is this distinction important? Meta-data concepts are a blessing and a curse. Its logical development permits simple and powerful human-database interaction. On the other hand, because changing the meta-data and the data model of the business enterprise is so difficult, meta-data are revised only under the most extreme circumstances.

Consider the following example of a database management system. A company determines it needs a database management system and uses data modelers to design the database. The model designed by the modelers includes an employee table in the database with associated meta-data appropriate for the firm.

Suppose the company's circumstances change and it now needs contractors, but the original data model is not designed to handle contractor personnel. How is this changed? It's not like saying John Doe was promoted so change his department and change his salary in one place. Meta data can be changed only by unloading all the company data, rethinking the data model, creating a new table type and re-populating it. And, of course, the system will be down while the changes are made. Often these types of changes are postponed until a "convenient time" which never arrives leaving the database in a state of patches and workarounds.[26]

Data-use:Data-design Dichotomy

When the distinction between meta data and data was created, a new distinction between the use and design of data was also enforced. Down at the data level, there are those who use, manipulate and maintain the data: the system users. And at a higher level are those who use, manipulate and maintain the meta data: the data modelers, systems analysts, database administrators, and data administrators. Most companies now have a Chief Information Officer (CIO) on a par with the Chief Financial Officer (CFO). A caste system has been created based on how the database is manipulated. Some people massage meta data while other people massage data. They are very separated, creating all sorts of problems for both communities in using the database.[27]

It must be remembered in talking about human-database interaction that data modelers as well as end users are accessing the data. Not only do end users have difficulty and lose time in querying the database, but data modelers, systems analysts, programmers, etc. lose productivity when they must struggle with knowledge (or the lack thereof) of meta-data. In most instances, those talking about natural language interfaces are referring to the end users. Rarely is the developer included. Any new paradigm must also address the programmer productivity problem, either from the standpoint of making it easier to access the meta-data or making programming more efficient. So, far the programming issue has barely been addressed. This paper offers some suggestions in this regard in the last section of the paper.[28]

5. DATA INDEPENDENCE

Returning to the time line of the evolution of database, Codd's main jump with the Relational Model was to go from physical to logical. Independence was an important aspect of the relational model. Physical independence means that the physical location in a database is irrelevant to the user. Tables can be reorganized to reclaim lost performance. It doesn't matter to the user. Back in the physical era it did matter because suddenly users wouldn't find what they were looking for where they expected to find it. Now users are addressing a virtual database, a logical one. What happens underneath it on the physical level doesn't matter. But what happens if the data model is revised to combine the salesmen and employees tables to reduce system complexity. Suddenly all the applications that were written for those specific tables don't work because they addressed the logical table. They were dependent on what takes place on the logical level and now they won't work anymore.

Codd added a mechanism called a view definition. Views are virtual tables. So if you have an employee's table you create a view that's just like it and all your applications address the view. If suddenly two tables are compressed into one, two view definitions can be created. One of the views would create a table that looks like the old employees table. The other view would create a table that looks like the old salesmen table. Both views would come from the new employees table. The applications programs would then run unaffected. But only if the applications were only doing queries. Unfortunately the view definitions are only partial. It's very hard to update the view. Most file maintenance operations are not permitted in views and, in fact, theoretical issues of updating views have not even been resolved. The primary problem is ambiguity.[29]

Relational View Update Problems

Maintenance of tables through views can create problems of ambiguity. Consider the following example. Suppose there are two real tables of departments and employees as shown in Figure 5. There are several employees in Department 2 but only one in Department 1. A view is created called emp_dept relational view. Emp_dept joins department and employee tables showing which employees are assigned to each department. Assume an update is made to the emp_dept view to delete employee 3008 in Department 1.

The following command is issued to emp_dept:

> Delete employee 3008

What should the view do? Obviously employee 3008 is deleted in the employee table? This is clear. But what happens in the department table? Since employee was the only employee in Department 1, is that department also deleted? The situation is ambiguous making the table not updatable or deletable through the view Emp_Dept. So what the view does now is respond:

> You can't update me.

Adaptive Layer Around Tables

Adaptive layers could be used to resolve update ambiguities. Consider putting an adaptive layer around relational database structures. Adaptive mechanisms should be used to resolve update ambiguities on views.[30] Continuing the example, if there were no specific rules in the adaptive system it might have to come back to the user and say:

> I don't know what to do. Do you want me to delete the department or not?

EMP_DEPT RELATIONAL VIEW

Emp_Num	Department_Num	Department_Name
3005	2	Sales
3006	2	Sales
3007	2	Sales
3008	1	R&D

EMPLOYEE RELATIONAL TABLE

Emp_Num	Department_Num
3005	2
3006	2
3007	2
3008	1

DEPARTMENT RELATIONAL TABLE

Department_Num	Department_Name
1	R&D
2	Sales

Figure 5 - Relational View Updates

But it wouldn't say:

> You can't update me.

Like it does today.

Or the database developer could have foreseen such a possibility and when they developed the application with this special kind of view they inserted a rule that said:

> In the event that one of the rows in emp_dept is deleted and there's only one corresponding row left in departments, keep it but log a message to this effect and send mail to the appropriate manager telling him this department has no employees.

The relational database was supposed to have logical independence, but did not. With adaptive layering around tables, technology can bring to the relational database something that it was supposed to have to begin with. In going from the physical database era to the logical, physical independence was achieved. An adaptive layer combined with these special kinds of disambiguating views on top of the relational model would be getting close to achieving logical independence. Something that Codd wanted to achieve but hasn't. Is this a signal of a new era on the time line of the evolution of database? The time line went from physical database that had no physical independence to logical ones that had physical independence. Perhaps this is the beginnings of a new database system, one that has true logical independence.

Relational database developers still have not achieved complete logical independence. Consider this. Physical independence is a two sided coin. One side enables the DBA to reorganize the physical level without impacting the users or existing applications. The other side enables users to address the database without knowledge of any physical details. Logical independence should also have two sides. The adaptive views discussed above enable the developer to reorganize the logical level of the database design without impacting users or applications (providing the developer makes appropriate adjustments to adaptive view definitions). But the second side of logical independence is absent - the user must still know the logical details of the database to use it - its specific structure and content. The kind of adaptivity we discussed first (e.g., conceptual pattern processing) can deliver this side of logical independence - but only if the database supports the adaptive mechanisms with thorough knowledge of the application domain and provides this knowledge in a flexible form that is useful to the adaptive mechanisms. Consideration will be given to what it will take to represent this real world knowledge in the following sections of the paper.

6. MODELING THE WORLD

The Relational Model

How appropriate are current database systems for modeling more than just data? To answer this we begin by returning to relational database and considering just what its elements mean.[31]

Interpretation of the relational model

A serious deficiency in the relational model is the absence of a type hierarchy. The relational model consists of just tables with rows and columns with an interpretation given as to what the tables, rows and columns are. The table as a whole is considered an entity type. So you might have employee entity type versus the department entity type or some other type. And some entities can actually be a relationship or an event. But they are considered to be entity types as well. If you happen to have employees and there are different kinds of employees - engineers, managers and sales people - they all have to go in one table. There's no way of saying that different kinds of employees have special qualities about them. They all go in one place. Each row is considered an actual entity and columns are interpreted as properties or attributes.

In extensions to the relational model (such as RM/T for Relational Model/Tasmania, where Codd introduced it in a database conference), it's possible to create a table with an hierarchy of types. For example, there could be an entity type for employees, managers, engineers, and sales people.[32]

The main employees' table could have columns in it, the attributes of each employee. The other tables such as managers, engineers, and sales would be subtypes of the employee table. As shown in Figure 6, arrows drawn to employees from managers, engineers and sales show the hierarchical relationship. The subset mark denotes subtype relationships. For example, managers are a subtype of employee; or employees are a supertype of managers. This is more convenient because columns (or attributes) in the sales table can be created for commission or commission percent.

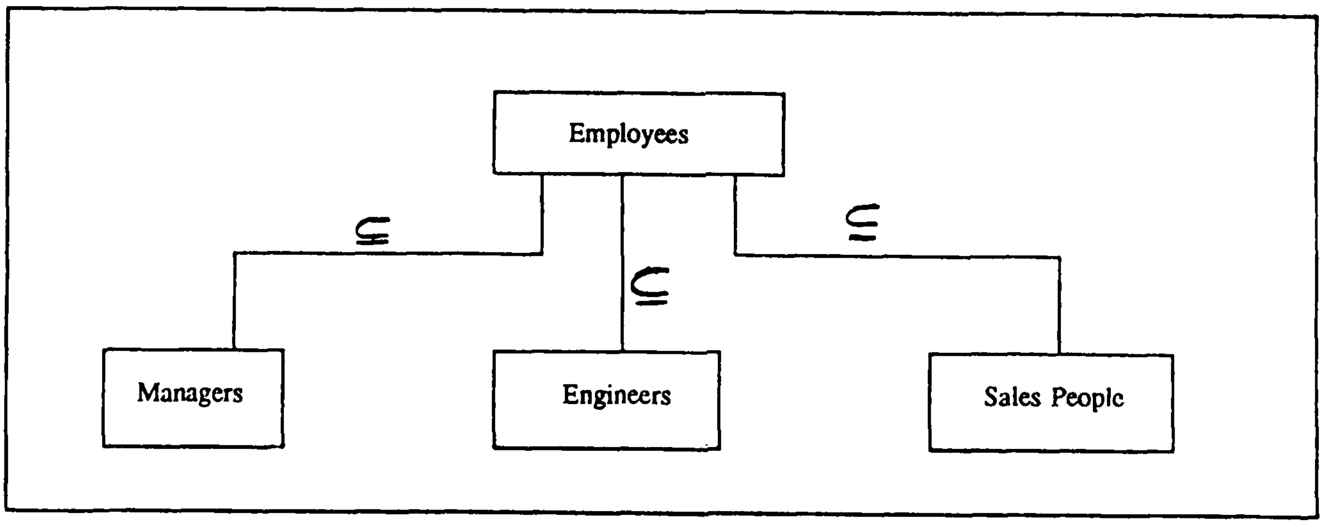

Figure 6 - Employees: Subtypes and Supertypes

In the managers table, columns for rank, or department managed could be created. Thus, the appropriate attributes can be distributed only where they are needed and not where they don't belong (as in tracking commission for managers). But there is a problem with this scenario. A different example illustrates this in the following section.

Lack of true inheritance in the relational model

Inheritance, as implemented in the relational model, requires the repetition of values for the inherited attributes. For example, consider the set of tables shown in Figure 7. There is one table for organisms. Below organisms, there is a subtype for animals. Below animals, there is a subtype for primates and below that a subtype for humans. Take a property such as metabolism. It so happens that every human being has a metabolism based on respiration. That happens to be true of humans but it's also true of primates. And, in fact, it's true of all animals. Although it's not true of plants which use photosynthesis.

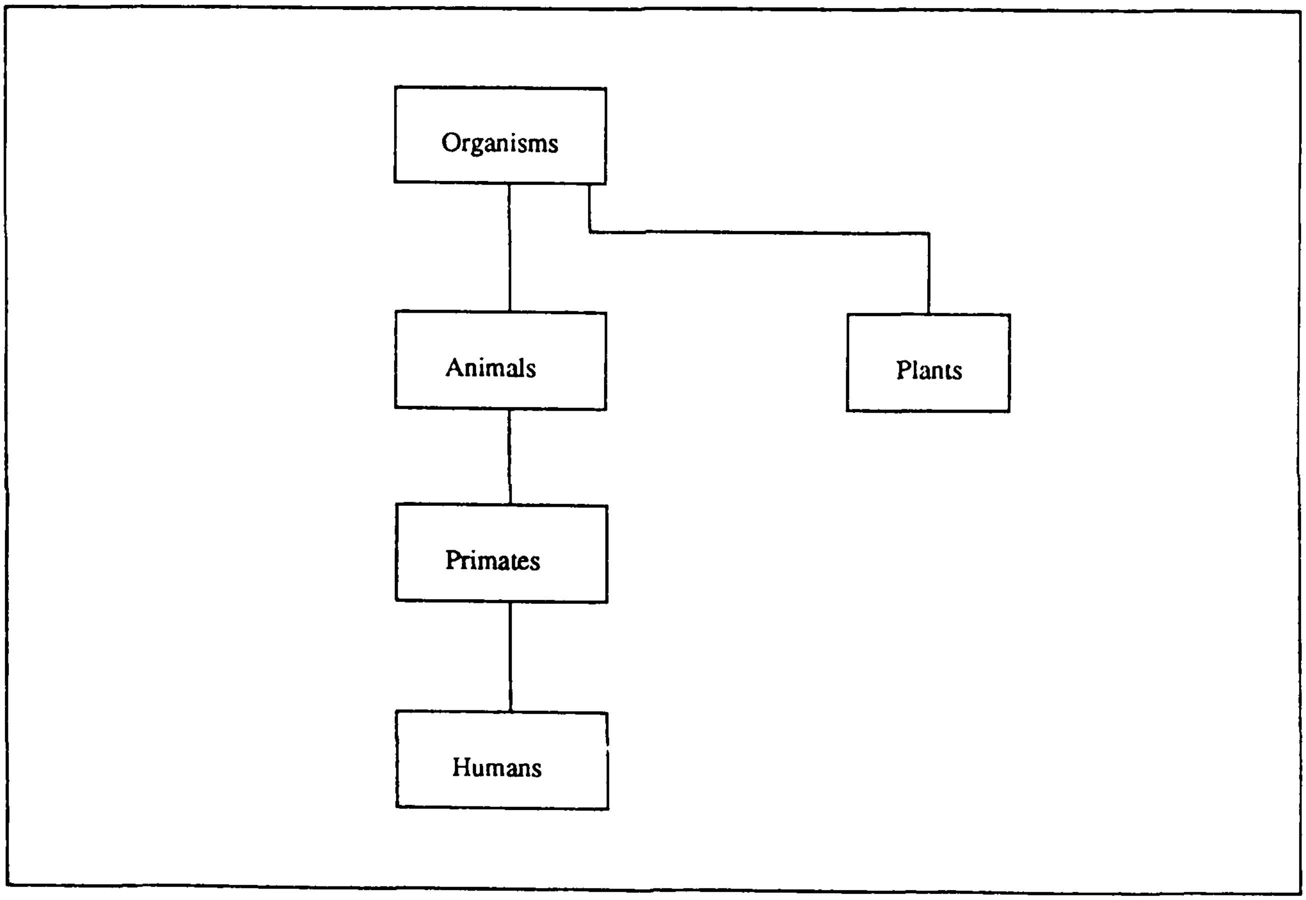

Figure 7 - Organisms: Subtypes and Supertypes

As shown, these have been placed in a hierarchy of types and all are tables. It's unfortunate but, for every row in the humans table, RM/T requires a row in primates, a row in animals, and a row in organisms. Under organisms there's a column type named metabolism with the value "respiration" for every row of each animal. That value must be repeated for every animal and every human being. The model will not allow us to designate that animals respirate in order to produce energy from food and have that property inherited by all its subtypes. This creates a tremendous amount of redundant information in the tables.[33]

The rather rudimentary method of inheritance illustrated above is ingrained in the relational model. Well, you can say, "So what? We'll have the computer repeat the values for us transparently so it doesn't take up a human beings time." There are two problems with this.

> Problem 1: If we're going to use adaptive mechanisms we need a more efficient form of assigning properties. Remember, we need to have numerous terms that have multiple meanings throughout this whole hierarchy.
>
> Problem 2: Very rarely can you classify things (that's the goal here), without exceptions popping up, and this is a lethal limitation of the relational approach.

Exceptions are forbidden in the relational model

Consider another type hierarchy with grey things, elephants, and royal elephants from Touretzky.[34] As shown in Figure 8, elephants are grey things and royal elephants are elephants. There's a problem though, royal elephants are not grey, royal elephants are white. Now, according to Codd, royal elephants would be a subtype of elephant and elephants would be a subtype of grey things and Clyde would be represented by a row in royal elephants, hence he must also have a row in elephants and a row in grey things. But Clyde is really a white royal elephant. So the relational model even in its maximally extended form cannot allow for this exception.

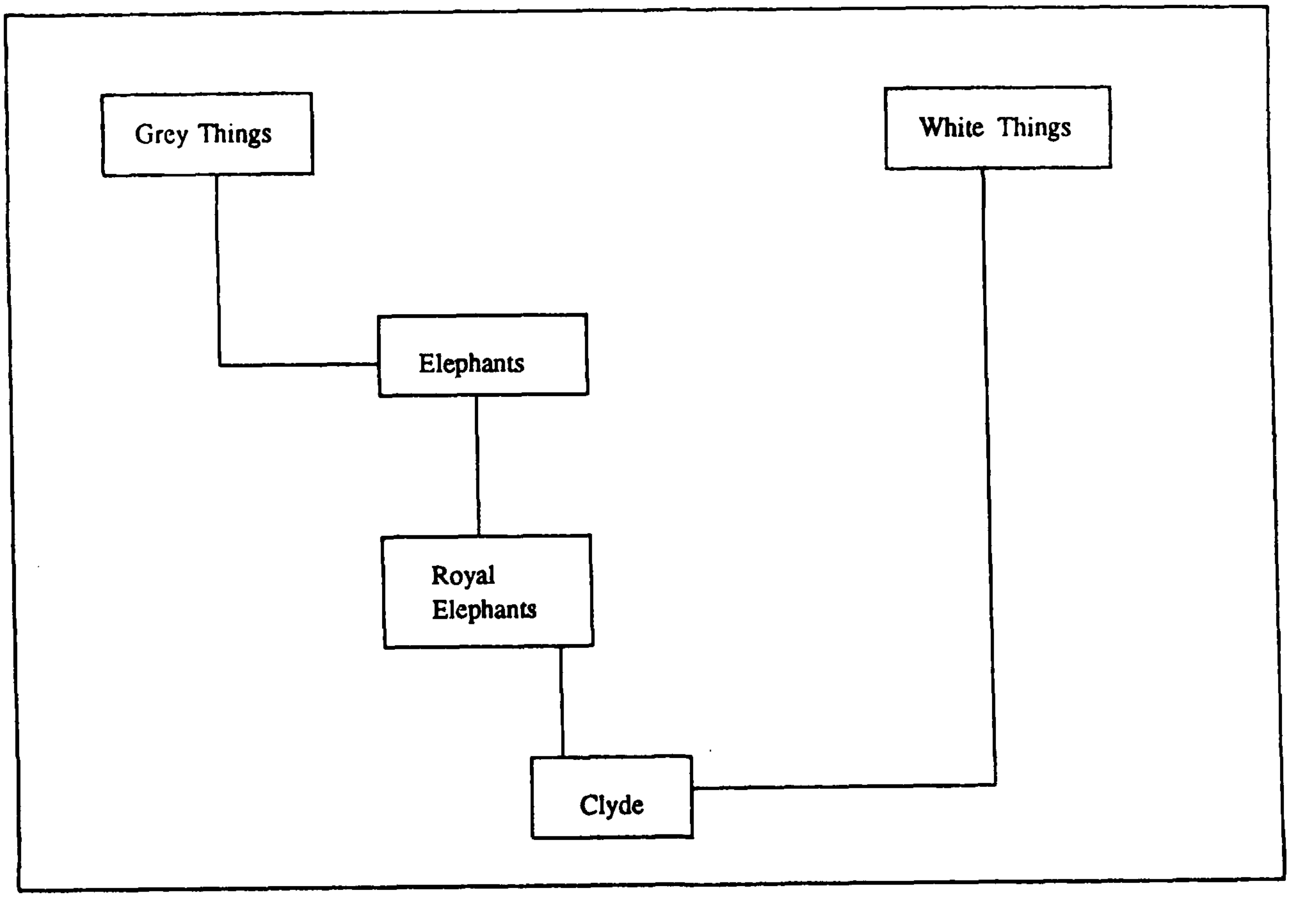

Figure 8 - The Exceptions Problem in Database

Another formalism is needed which allows for typing and subtyping but doesn't require storage of redundant information as illustrated in the human being example above, e.g. every human being in an organism table has to have respiration as their digestion system and energy producing mechanism.

A completely different form is needed, one that has representation of exceptions as a simple, natural extension. Artificial intelligence was mentioned earlier as a major topic of prehistory that has developed along a path independent of database research. There are several areas of artificial intelligence that can be useful if applied to a new model of database management.[35]

Semantic Networks

Semantic networks have long been a major topic in the artificial intelligence community as a method for showing type, supertype and subtype relationships through nodes, links and an inheritance mechanism. The definition of semantic is meaningful, or having meaning. The definition of network is a certain mathematical structure of nodes and links. Nodes are repositories of an abstraction from the model and links are arbitrary single line connections between nodes. Networks are a very general idea and there are numerous types.

The kind of network used in a semantic network is a directed acyclic graph (DAG.) Directed means the nodes connected by the links are assigned a direction. They point from one node to another node in a specific way that remains unchanged for the life of the model. Acyclic means there are no closed paths in the network, that is, you cannot start at some node in the network and return to the starting point without lifting your pencil from the paper. A graph is a very general idea in mathematics which simply means any structure formed by nodes and links (not just the familiar x-y plots.) A DAG can have a visual (see Figure 9) representation of the nodes and links. The visual representation is optional (but very useful for human understanding) because the DAG can be represented in various mathematical forms, e.g. matrices. This last property of DAGs make them especially useful for modeling, because the mathematical representations can be manipulated by computers, hence their popularity.[36]

Inheritance in a semantic network is defined in such a way that properties (attributes) of a higher level object do not have to be repeated in lower level objects. These inheritance characteristics are represented by the directed links (also called arcs) between the nodes in the network. Links are given names such as "is-a" and "a kind of" (ako) showing the direction of inheritance. A detailed discussion of inheritance is beyond the scope of this paper.

Inheritance with exceptions

The semantic network can represent inheritance with exceptions as a natural extension of its form. Reconsider the elephant example shown in Figure 9 below as a semantic network representation. There is a node for grey things, another one for elephants, and a link denoting elephants are a kind of (ako) grey thing and Clyde is shown as a kind of elephant. Furthermore, royal elephants are shown which are a kind of elephant and Clyde is shown as a royal elephant. Royal elephants are elephants but they are not grey. The addition of an "is not a" link from Clyde to grey thing makes Clyde an exception to the property grey thing. But how do you tell which path is the inheritance path?[37]

David Touretzky developed the algorithm of inferential distance ordering to determine the inheritance path in cases illustrated by Figure 9. For example, the distance of inferring that Clyde is not a grey thing along one path is 1. One link away. The distance of inferring that Clyde is a grey thing along another inference path, is 2 (two links away.) Inheritance is defined along the inference path with the shortest inferential distance order. Clyde is inferred not to be grey because that inference has the shortest path.[38]

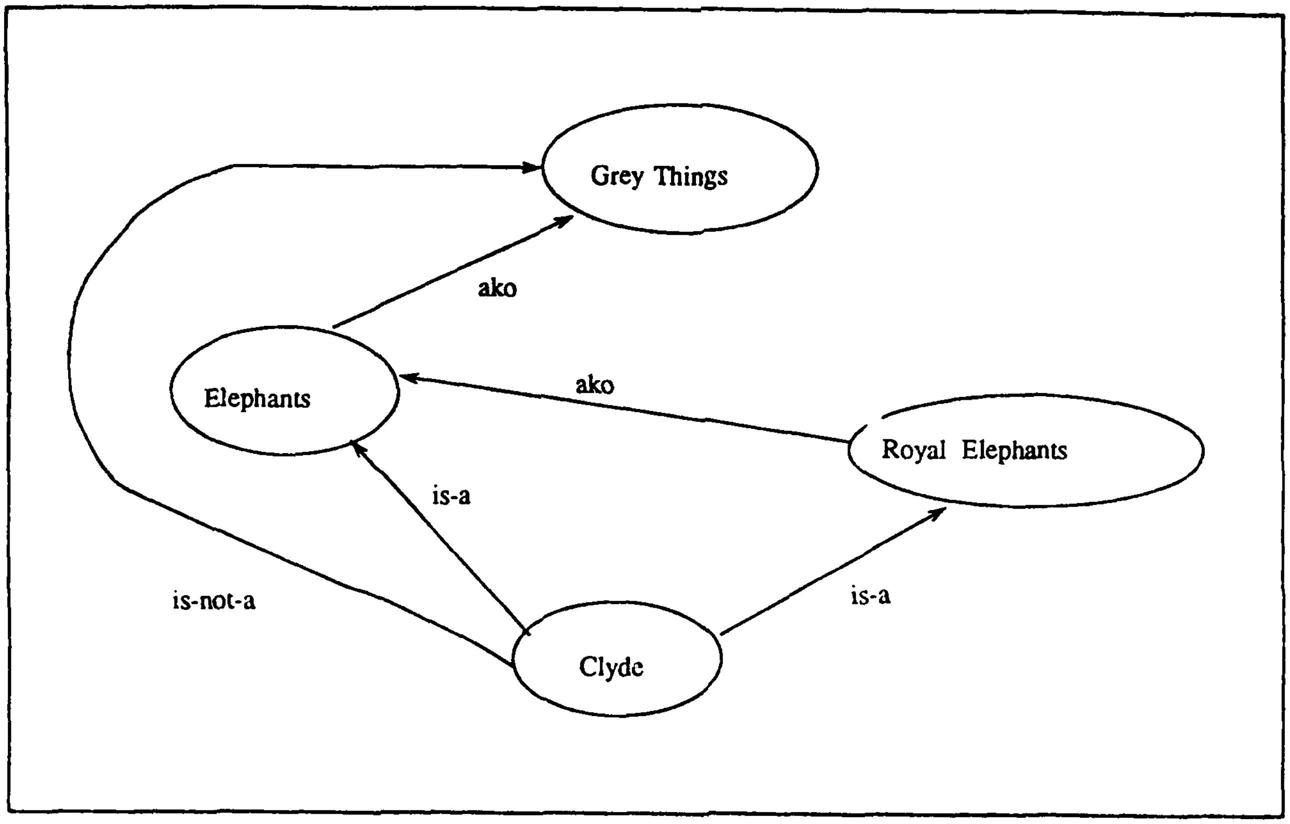

Figure 9 - Inheritance with Exceptions

There are examples, of course, where the inference isn't clear. Consider the example shown in Figure 10. As shown there is a semantic network of quakers, republicans, pacifists, and nonpacifists. Quakers are a kind of pacifist, republicans are a kind of nonpacifist. Nixon is a republican. Is he pacifist or nonpacifist?

Notice the unique difference here between these two examples: the elephants and Nixon. In the elephants example: if you consider elephants, there are two paths you can follow away from elephants to things that are more specific. You can go from elephants to a subclass, royal elephants, or you can go from elephants to a specific instance of an elephant, Clyde. But in Figure 10, Nixon inherits properties from two entirely different nodes. When an object inherits properties from multiple parents, it is called multiple inheritance. In this example, Nixon inherits properties from being a republican and he inherits properties from being a quaker. In other words, in multiple inheritance a single node (Nixon) has multiple parents (republicans, quakers.)

If the inferential distance ordering algorithm is applied to the example of Nixon, the same number of inferential steps to the inference that he is both a pacifist and a non pacifist. In this case inference difference leads to ambiguity, but at least the network accurately determines the ambiguity and fails gracefully. This then defines a viable method for handling exceptions.

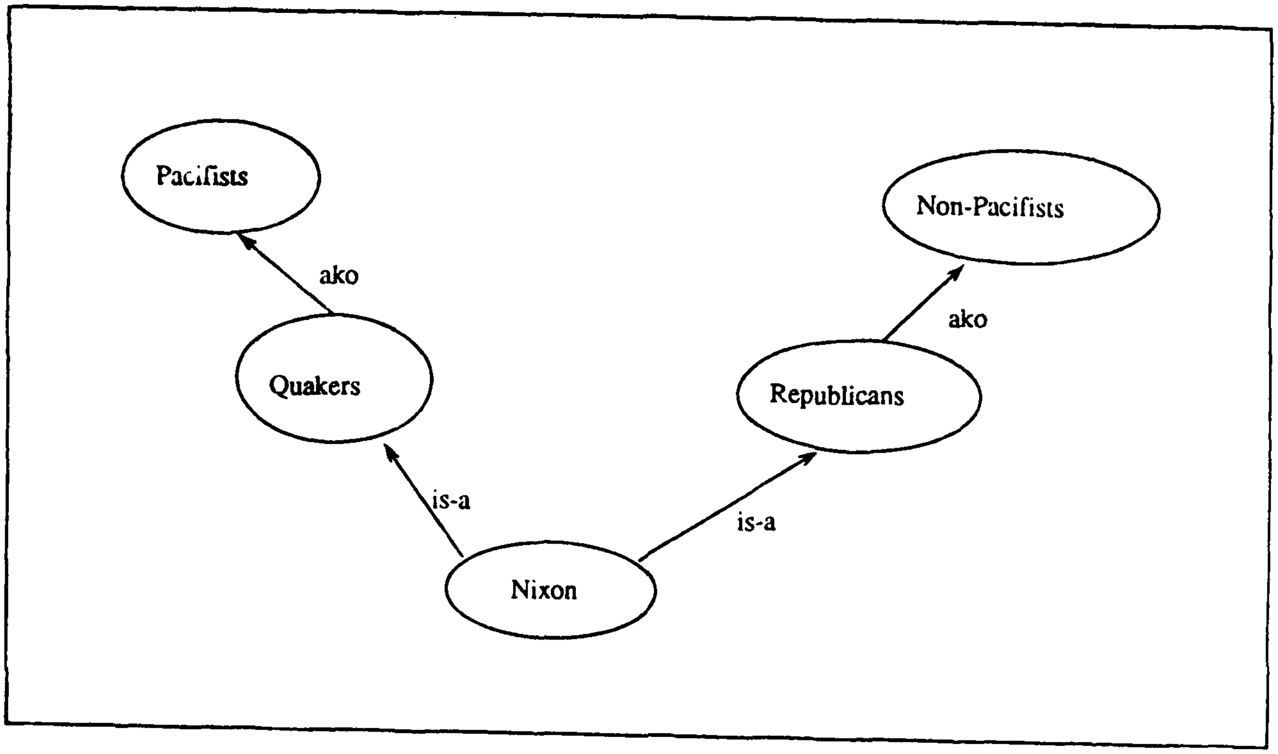

Figure 10 - Ambiguous Inheritance

Inheritance and exceptions handling in semantic networks are much superior to the relational model, because in order to say that everyone has respiration as their method of producing energy you only have to attach it one place, the highest category it belongs to. In the organism example that would be to animal. Animals in general and everything below animal life will inherit respiration unless it is cancelled out by an exception. Another example is birds that have the characteristic that they fly. And there is a subclass of birds, penguins, that do not fly. The "fly" property is cancelled with a link saying: yes, they're birds but they don't fly. this exception can be handled and it can be used in reasoning.

Notice also something else. In this scenario of semantic networks there is no distinction in how we represent data from meta-data. An instance like Nixon looks just the same as a class like quakers, republicans, etc. That means that the same person uses the same tools for working with data or meta-data. There is no distinction. That's a great advantage. It means that if you need to change employees into contractors you do it in one fell swoop. It also means that your whole model can evolve slowly over time. It doesn't have to be created fully evolved, providing all the meta-data for the system and then populating it with data. It evolves naturally.

The problems of link based relationships

Link based relationships have two problems: 1) efficient implementation and 2) we have created a new dichotomy. Properties and relationships are now links while types are nodes. You say "they are different things, so why can't we express them differently?". Problem: All these nodes get modified and classified by how they fit in the whole network structure. The meaning of elephants is dependent on all of its subclasses such as royal elephants, Indian elephants, or Canadian mountain elephants. All of its specific instances and it's the instances that define everything.[39]

You've probably heard it said that language is entirely arbitrary. And of course there's a whole bunch of philosophers that want you to believe that. But it isn't totally arbitrary. You can use any term you want to designate anything but at some point your meaning eventually comes from the real world, from entities and actions and relationships and experiences in the real world. The measurements in the real world. So every node gets its meaning. It inherits its meaning from the way it sits in the whole network.

What about color? How do we say that color is in fact a subtype of the concept property? In fact a measurement made on certain electromagnetic radiation emitted by or reflected off an entity. Well, we can't hook a "a kind of" link up to a color link and hook it up to a supertype property link. The problem is links don't inherit meaning through the network the way nodes do. And if color is to be treated like Nixon, color must sit in the whole network structure and inherit its meaning and definition from its position in the structure. To achieve this goal, consider again the relational model to analyze one of its strengths.[40]

Value Based Relationships

The genius and strength of the relational model was to allow the data to drive the relationships. These data are the values in the various attribute columns. With the relational model, there is a collection of tables linked through values. Unlike the earlier physical database era systems which relied on hard connections between different files, whether in a hierarchical order or free-form network, relational table links are not pre-specified. With physical files, the path to the file location had to be known and it had to be specified in the query. But it wasn't really a query. It was a program in COBOL. That's why when a report was needed, a programmer wrote a program to extract the necessary data. Often these programs created a backlog in the data processing department causing queries to take a week or more to be returned. In the relational model, a user with knowledge of the meta-data can do equivalent retrievals with a single line command in a 4GL. The following paragraphs examine the nature of values and how they are used in the relational model.

Values as measurements

A value is data entered into the attribute fields of a database system. Or in another scenario, a vision program might scan for data for input to an artificial intelligence program for interpretation in the context of machine vision. Or chemical analysis data might be picked up through real time sensors as measurements for later analysis. Values can be direct measurements as in real time sensing or the values may be indirect measurements as an employee's salary.[41]

Values that have been measured in terms of similar units may be compared and the comparisons used in establishing relationships in the data model. And if they are not similar units, but the units are known, a conversion between units can be done (e.g. compare English pounds to American dollars through the monetary exchange conversion.) The values do not have to be the same column but they do have to be similar data types. One must compare apples to apples. Or if comparing apples to oranges, there needs to be some means of conversion but only if there is some metaphysical similarity. Even if certain things are expressed in very different units, if they are metaphysically related then it's possible to convert one to the other then do the comparison.

The importance of establishing relationships based on value comparisons is that all possible relationships do not have to be anticipated when the data model is constructed. The relationships can be created on the fly by a user with knowledge of the meta-data of the model. As the values change, the relationships can change.

Implicit and explicit relationships

In relational database there are no pointers. There are just independent tables with values. If an employees' table and department table exist, every employee could have a department number as one of their columns, among other columns. And in the department table, of course, there ia a column for department number, department name, etc. Technically there are no explicit connections between the two tables. But there are many implicit relationships and it's up to the queries to activate those implicit relationships.

For example, the fact that someone is wearing blue pants and blue shirt has an implicit relationship - a similarity in the color between the two garments. It's not explicit, it's implicit and humans recognize it unconsciously. A passer by doesn't have to anticipate it. Similarly, the strength of the relational model is grounded in the fact that the relational model of data is value based. Many implicit relationships can be captured and later extracted later by a user looking to discover them without explicitly programming them. The programmer is freed from having to anticipate every possibility and programming for every contingency.

Consider the example shown in Figure 11. There is an implicit relationship between the department column in the employees table that has the department number = 1 and a row in the department table that has department number = 1. At some future time, a user could bring this relationship out and make it explicit by comparing these values to find all employees who work in Department 1.

Employees Relational Table

Emp_Num	Department_#	Salary
2001	1	240,000

Departments Relational Table

Department_#	Department_Name
1	R&D

Figure 11 - Value Based Inference

Value based inference

In a different example consider one table that has salaried employees with their salaries, another table that has the sales force with their end-of-year commissions. These two columns (salaries and total year end commission) happen to be of the same data type. They are both measured by the same amounts, the same units, i.e. dollars. Someone could come in (the database designer never having anticipated this) and by comparing the values in their respective columns determine who is making more money, the sales people on commissions or the salaried people including our chief executive officer. This is illustrated by Figure 12.

Salaried_Employees Relational Table		
Emp_Num	Department_#	Salary

Sales_Force Relational Table		
Emp_Num	Department_#	Total_Commission

Figure 12 - More Value Based Inference

By doing a relational join operation, one could make explicit the relationship between salary and commission. They might do a theta join looking for values related by inequalities, such as "Show me every salesman that earns more on commissions totally than our directors do based on their salary". That person is making explicit a relationship that heretofore had been implicit and only had been values with no real physical connection.

Value Based Semantic Networks

The authors have synthesized value based relational models with semantic networks to create a value based semantic network. This synthesis takes the best of the relational model and combines it with the best of semantic networks. This work grew out of the authors' observation that relationships and attributes are second class citizens in semantic networks, but there was a lot of good in them that could be made better by abstracting the value based approach from the relational model and using it to reshape semantic nets. This new class of model has been named Value Based Semantic Networks. These networks do not have links. They have nodes with values in them that express implicit relationships in those values and it's up to the user or a computer program to make certain relationships explicit. The advantage is that they place properties, relationships and events on equal terms with entities and types.[42]

Value based semantic networks example

Consider a room with a floor and ceiling as an example of the generic relationship of one entity located above a second entity - the above/below relationship. In the value based semantic network, a formalism is created that can model the hierarchy of relationships. Just as entity types, such as royal elephants, elephants and grey things, were modeled, relationships are given full status in the model as nodes. The relationships can then inherit properties in the same manner as entities. The specific floor beneath our feet and the specific ceiling above our heads is a specific instance of the generic above/below relationship just as this specific floor is an instance of the generic entity type floor.[43]

Figure 13 shows a value based semantic network. Starting at the bottom of the figure, a node is a specific reference to a specific floor. The term in Figure 13 of specific floor is not necessarily in the node. It could simply be a reference to a synonym list elsewhere in the database that handles vocabulary.

Borrowing a concept from the relational model, a surrogate number for identification will be assigned to each of the entities and relationships in Figure 13. This number is assigned by the system and is completely unique. It is often referred to as a surrogate key. The users never deal with them, never change them, there's no referential integrity problem. These surrogate keys will be used throughout this example.

9. Conceptual Unit Relationships (8,3)
8. Concept - General Above/Below Relationship (5,4)

7. Conseptual Unit Relationship (5,2)
6. Conceptual Unit Relationship (4,1)

5. Concept - General Ceiling
4. Concept - Generak Floor

3. Specific Above/Below Relationship (2,1)
2. Specific Ceiling
1. Specific Floor

Figure 13 - Value Based Semantic Networks

The specific floor in the model is 1 and the specific ceiling is 2. There is also a specific relationship between the two. It's the specific above/below relationship, 3. It has two other values to designate the entities related by the above/below relationship. This is a specific instance of an above/below relationship. And depending on how you read it, either 1 is above 2 or 2 is below 1.

Notice these nodes are not physically linked. But if one wanted to join them one could find out that our specific floor is in fact below our specific ceiling. Because there is a specific above/below relationship, the model will require a general above/below relationship, 8. Node 4 is a node for the general concept of floor and the general concept of ceiling is 5.

A very special recursive relationship, called a conceptual unit, creates a relationship between a concept object and an instance of the object. (1286, 1291) This special relationship replaces the links of a semantic network. The two values in the relationship designate the "logical links" between the concept object and the instance of that object. As shown in Figure 13, conceptual unit

7 relates the general ceiling 5 to the instance of specific ceiling 2. Similarly, conceptual unit 9 relates the concept of above/below 8 to the specific instance of above/below relationship 3.[44]

Figure 14 shows the problem with attempting to model this example with normal semantic networks. They cannot handle the inheritance of relationships because relationships are handled by links which may not be hierarchically classified in the network.

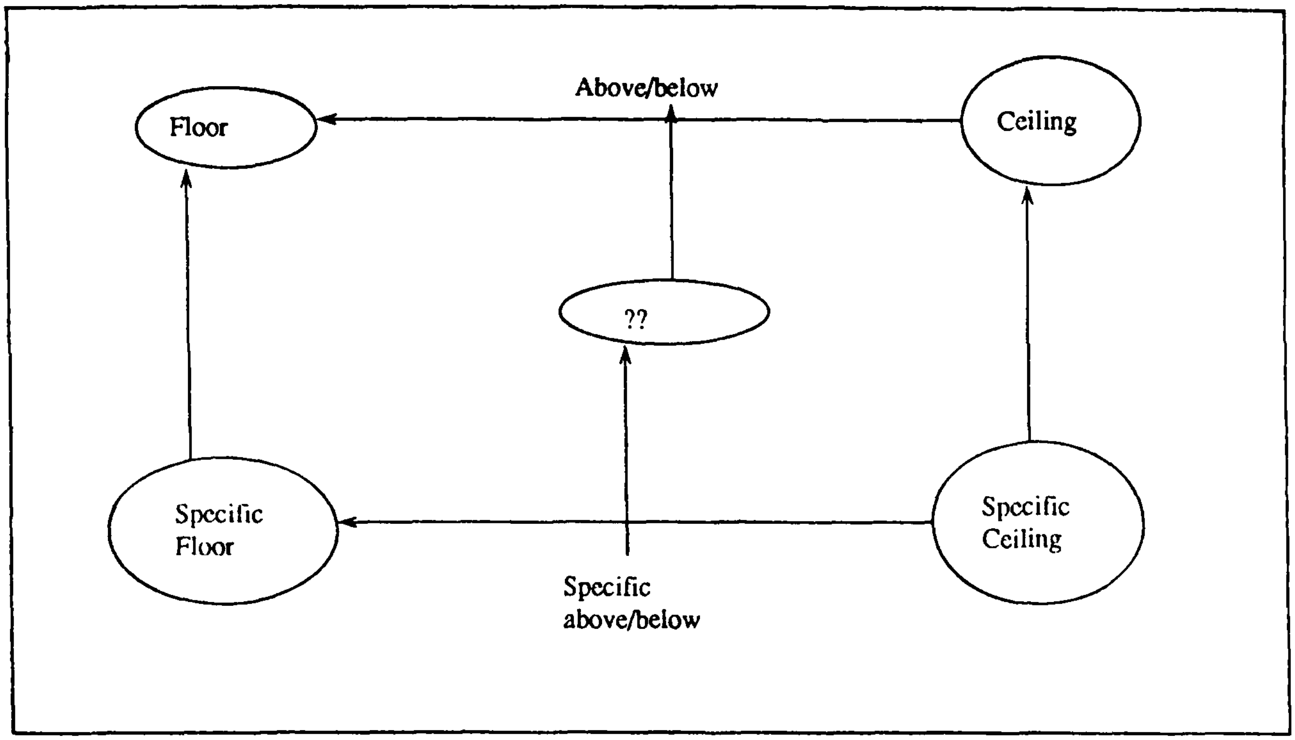

Figure 14 - Link Based Semantic Networks

We want representational formalisms that give us as much expressive power for dealing with relationships as they provide for handling entities. A relationship that you could make an instance or a superclass or a subclass and properties can be inherited. You can have very complex relationships involving many things at one given time. This formalism allows for this complexity while allowing exceptions and taking advantage of the value basis.

To implement this model in a relational database system, all nodes would be rows in various tables. The system would not be a very efficient system doing that because there would be numerous join operations. Unless you have the right hardware, that is.

Hardware Considerations

The purpose of this study was to discover how to achieve certain objectives of human database interaction such as adaptivity and flexibility in order to avoid query failure. To do that a sufficiently strong representational formalism was needed in the database structure. Now, taking a further step, it should be noted that to do value based semantic networks efficiently, a special purpose hardware platform is needed to support these very expressive flexible formalisms.[45]

A massively parallel processor is needed where each individual processor can have one or more of these value based node units and all of them can communicate simultaneously with one another to make their implicit relationships explicit. For example, a computer like The Connection Machine from Thinking Machines Corporation is needed. Additionally, value based relationships are better suited for execution of queries in parallel than relationships represented with a link-based formalism (e.g., Find all sons who are hated by their fathers.)[46]

7. INCOMPLETE AND UNCERTAIN INFORMATION

There is one kind of representational problem that the preceding formalism is not going to solve. It's probably the most difficult problem of database management modeling, and therefore human - database interaction, that there is. That's the area of incomplete information and uncertain information. It's a lot deeper than can be handled with null values for missing information or a certainty threshold like in an expert system. Because not only can data be uncertain, structure can be uncertain and above all the domain can be uncertain.

At some point in time database management is going to face a crisis similar to what physics faced in the late 1800's and early 1900's - where there are domains which can describe some of the gross superficial behavior but cannot accurately divide it into components and how they relate. it cannot be particularized. Even the latest technology, object oriented programming is taking a particle view of data. This approach of value based semantic networks is taking a particle based approach. It's not the ultimate solution and if you wonder how the quantum domain has any relationship with anything you normally deal with, think about the problem of corporate information managers and IRM (Information Resource Management.) How does the corporation take the aggregate of business functions and understand it as a collection of individual discrete components that interact with each other and work together? The boundaries are fuzzy and foggy.[47]

8. THE NEW INTERFACE PARADIGM

A natural language interface, even under the best possible conditions, would not give a human-database interaction as effective as human-human interaction. Because human-human interaction isn't just verbal; it's verbal and visual. It relates on a physical context, not just a verbal context. What that means is if human-database interaction is to be as effective as human-human, or better yet, more effective, it can't be constrained by the verbal medium or, even worse than the verbal medium, the textual medium. The interface needs to be opened up to all human senses, to an experiential meeting with the database. In the following sections, this study will offer approaches to designing a new interface paradigm based on value based semantic networks in order to make use of full experiential interaction with the database.

Human Beings & Information Processing

Human beings process information on three simultaneous levels: the sensorial level, the perceptual level, and the conceptual level. To some extent man operates on the sensorial level. He is not generally aware of sensations all by themselves but he can be under suitable conditions such as psychological experiments involving the senses. He is aware of one sensation as opposed to the nothingness of a following sensation under the right conditions. But even without higher brain functioning, the lower brain can take sensations and abstract (in other words, make explicit) relationships that are in them. And that is a perceptual level which gives rise to perceptions as opposed to simple sensations. Notice that animals (although they are not intelligent in an abstract sense) are extremely good at doing perceptual tasks. A driver wouldn't let go of the steering wheel in a car driving through a forest but he can let the reigns loose with a horse. The horse is not going to run into a tree.[48]

Beyond that, man is also able to abstract from his perceptions and form his concepts. His conceptual apparatus. Now despite what Immanuel Kant has said, this conceptual chain is how he gets around in the world and how he thinks. Despite what a lot of philosophers and psychologists would say, man is not operating purely conceptually. It's not like he starts as a baby (sensorial), moves up as a youngster (perceptual) and ends up living only on the conceptual plane as an adult. Man in his world operates in all three planes simultaneously. This is the Conceptual Chain.

As a gedanken experiment, try to think of the concept elephant without thinking about some part of its perceptual appearance. Try to think of a perception without a concept. It's all interlinked together. For this reason, there are two important things to consider.

The first is that humans need to be able to interact with databases on all levels. To the database, the sensorial level is the area of measurement and data values. The conceptual level in relational databases is the database schema and meta-data. Right now there is no perceptual level, it's stripped away because designs have gone from the real world to data and then to meta-data. The connecting medium has been thrown out. It would be beneficial if humans could interact with the database on all levels. That means, for example, if a user wants to make a reference to something he shouldn't have to limit his references to terms, he might use perceptions.

The second is, it might help to architect database systems in senses that emulate human senses. This would require the integration of disparate hardware technologies such as vision. All of man's high level concepts are ultimately related to measurements taken in reality. There is hardware for taking direct measurements in reality and assembling them and making sense of them. Neural networks and genetic algorithms processing signals from vision or aural devices might be used for the sensorial and perceptual levels of the database.[49]

By utilizing the conceptual chain, researchers have a way of tying in vision and visual/graphical drawings, pictures, etc. into the knowledge network that's represented in the value based semantic networks. If a person needs to be able to do database query, he should be able to use not just natural language but be able to point to a picture with the picture having meaning in the database. The value based semantic network shows how item are related to other nodes in the network. In the case of the ceiling and floor example, the specific ceiling has certain characteristic properties which can be measured and their values put in the database but the images could be there as well.[50]

If someone said in a query:

> I want to know what is below that. (pointing at a picture that is on their screen)

the system could track it back to its specific relationship, find out what other things are, find out that happens to be a specific ceiling that they pointed to, find out what things are below that specific ceiling and either tell the user or bring up pictures.[51]

Self organization with the database autonomously accepting information and organizing it is not necessary at this stage. This would require some kind of neural network or adaptive algorithm. The system would still have people putting the information in but in a much friendlier environment, much more expressive, and at the a perceptual level of object description. Users are not dealing with data anymore, they are dealing with the world again.[52]

Leveraging the Human Synergy

Consider one more area of opportunity. Man operates on three levels including sensations, perceptions and conceptions. He is not just a perceiver and receiver. He also participates in his environment. He is extremely good at fine motor control. Excellent hands and feet and legs for doing things. A good case in point is an operator of a tractor or construction equipment. They use most parts of their body in operating their device. Right now our database system users are using their fingers on a keyboard and maybe one hand operating a mouse. Or maybe a finger on a touch screen. However, if the effectiveness of human-database interaction is to be really improved, interfaces which utilize all the interface options that a human being offers must be created.[53]

The Road in the Sky

An example of one situation that takes advantage of man's conceptual, perceptual, and motor control is the "Road in the Sky" example. Consider the typical fighter plane where the pilot has to decipher many gauge readouts, make computations based on these, and look at various devices that determine how far he can go, where he can go based on wind currents, how much fuel he has left, where there might be enemy territory, where he has to fly to avoid radar, etc. Why should he have to decipher all of this when instead the computer onboard the plane can take these, make the calculations, and project on the canopy in front of him, in the sky, a road with representations of enemy areas, etc., showing him where to fly. He can now basically fly by a computerized seat of the pants much as the aces during WWI would, but under much more compelling situations than WWI fighters ever encountered.

Database Access

Of course, the subject here is not pilots accessing databases, but users accessing databases should be able to do something more like the road in the sky. They should not have to deal with data but with the domain of the world that they are investigating. Not dealing with a model of data but with a high level model of what they are interested in, and if that particular domain makes use of sight, sound, touch, and smell - utilize all those senses.

Hardware technology is evolving rapidly in the areas of transceivers and transducers. There is currently an interface using a glove that an operator wears, it has detectors to sense the wearer's hand positions and arm movements and reproduce these on a screen in front of him to the extent that now with his glove hand he can reach out and pick up objects that are actually on the screen. Not in reality. It's not quite the Holodeck on the Enterprise in Star Trek: The Next Generation, but it's heading in that general direction. The important thing to say is that to support that, once again, we need the representational formalism underneath that we've been discussing and we need the hardware support under it to make it fast enough and give us the performance.[54]

9. THE NEXT STEP

The analysis and synthesis of this study has produced promising directions. In this section a future development model will be discussed that provides directions for future research in database management techniques. As shown in Figure 15 there are three different directions that need to be pursued based on the analysis of this study. Like previous eras of database evolution, there are two increments of development: an initial increment of new concepts and a subsequent increment of cross fertilization and maturation.[55]

RESEARCH & DEVELOPMENT MATRIX		
	Increment 1 New Concepts	Increment 2 Maturation
Direction 1 Building on Existing Foundations	Adaptive Relational Database Adaptive, Active Thesauri for ISARS	Adaptive, Value Based Semantic Networks for General Modeling with Direct Multi-Sensorial Interface
Direction 2 Building a New Foundation	Value Based Semantic Networks	
Direction 3 A New Interface Paradigm	Visual/Graphical Thesauri	

Figure 15 - Research and Development Matrix

The first direction implies value based semantic networks are not implemented right now. Current technology is fully relational database management systems and fairly sophisticated on-line information storage and retrieval systems. The next step should take them and build on them as much as possible. In other words - take the best existing foundations and build on them in promising directions.

The second direction implies the best of the existing foundations has many weaknesses and ultimately will be insufficient to achieve fully integrated interface goals. Researchers need to start work on constructing a more solid foundation. A suggested model for this direction is the value based semantic network.

The third direction is a new interface paradigm. Up to now - with database - all users are interfacing with data through data models. An interface paradigm is needed at a higher level. It is not the information level as in the data, information, knowledge, wisdom progression; but it is at a higher level.

Adaptive, Active Thesauri

Direction 1 in Figure 15 is split into two halves. One is focusing on structured database management systems, the other is focusing on unstructured information storage and retrieval systems. The goal in increment 1 is to make these systems more adaptive and to prevent or offset query failure. In the process to make them more flexible and make it easier for developers and users to use them. Ultimately, the data and meta-data dichotomy must be synthesized.
How can this be accomplished? The best foundation is the concept of a thesaurus. A thesaurus, at its best, is a network - not just a tree, but a directed acyclic graph taking terms or concepts and relating them to each other through narrower term, wider term and related terms. Ultimately, the thesauri can have one concept with multiple terms attached to it. And take one term and relate it to multiple concepts. So far all the current thesauri operate manually. For example, suppose a medical researcher is investigating the term bronchitis. If he tried a query with bronchitis but didn't get what he wanted, he could look it up in the thesaurus and say "I need something more general". Go up the wider term link and find something more general and substitute that into the query. Or maybe he got too many responses to the query. He could go down a narrower term link.[56]

The thesaurus could be automated, as has been shown in Proto-Atlas, by implementing a value based semantic network. Proto-Atlas offsets query failure, is flexible, and doesn't require users to specify or have knowledge of meta-data. It doesn't force the user to know exactly what they are after because if they did know, they wouldn't be using the database.[57]

Adaptive Relational Database

In the area of database management systems, the strongest foundation available is relational database management systems. Near fully relational databases are currently available such as: IBM's DB2, release 2; Sybase; Oracle; etc. These database managers meet most if not all of Codd's rules for relational databases, supporting concepts such as referential integrity and views. Within a year of today, there will likely be quite a few products available which are fully relational. The need is to encapsulate such a database system with an adaptive layer.[58]

How can the adaptive layer on top of relational databases be accomplished? One rich collection of methods is object-oriented programming paradigms. These seem to be the best available methods at the moment because of the code reusability they encourage - being able to take objects (self-contained packages of program code) and allow other people to use them and embed them into other applications. Clever programmers take them and make more specific uses of them other than the original one for which they were intended.

Using today's distributed architecture

Consider the relational database and the example of the employee table. Assume it is running on a general purpose machine running a database management system such as DB2. Assume also a front end interface machine such as a 386 workstations like IBM PS2 model 80s or Motorola 68000 based workstations such as Sun or Macintosh running interface programs at the user location. Smalltalk-80, an object oriented programing environment, could be used to provide much of the functionality described in this study for the front-end interface. With DB2 running on the backend and efficient network hardware and software for connecting the two, an environment exists which is exploitable in today's world.[59]

An object oriented environment can have hierarchies. A window object can be created with a subclass of a data entry form which contains a subclass of an entry form for employees. Someone programs the code for a general purpose window object and from then on it exists in an object library for all to use. Someone else says "I need a data entry form and it needs to be a window." They take the window object and create a subtype of it. They add more code to it. Then someone says "I really need to maintain equipment data", they take that data entry window class and create another subtype - one for entering equipment data. When an application demands one of these an instance of the object is made to support the application.[60]

Notice the specific screen is not rewritten from scratch. Existing code is used from the library it is expanded to the new requirement to get the specific functionality. Because the employee data object is lower down the inheritance hierarchy, it inherits behavior from the window class higher up. The objects are not only inheriting their properties, as in a semantic network, they are also inheriting their code.

Exploiting the object-oriented paradigm

The object-oriented paradigm can be exploited to communicate with the database. Suppose a table object is created. The table object has embedded in its programming code, whatever calls it needs to make queries and send commands to the database system over the network and to format data which returns. But to the programming environment, Smalltalk for instance, it doesn't look any different than the actual table. This creates a virtual database table in the Smalltalk object oriented environment. Other things can be done with that table object. But the paradigm can create something more sophisticated. If the underlying database is not fully relational, perhaps it doesn't support referential integrity or domains, a special relation object could be created which looks like a table, refers to the table object and adds functionality to it. In this way the table object has been used to create a higher level object that relates to it and adds functionality.[61]

The process of building objects can continue to higher levels. A special purpose relation could be added. For example, suppose the application requires the tracking of dates and times, to add temporality. Temporality is not a basic part of the relational model. But create a class of objects can be created that have temporality as a basic feature. If you need a special table that's temporal, you make an instance of this class, it will make instances of the relation object, table object and define the SQL queries on the back-end database machine. The interface sends messages in the object oriented environment to the special purpose relations.[62]

The next logical step is a composite object. A composite object is an special purpose relation object with a small expert system that does disambiguating. The composite resembles a view but resolves view update problems. It's updatable and deletable. The expert system has special rules in it for disambiguating as desired. The rules could be stored in a special dictionary in the back-end database machine and made callable from the front-end object-oriented interface. This composite object can contain the adaptivity code. The code that - if you put a query to this composite and something is spelled wrong or you unknowingly violate real world constraints it can handle it with conceptual pattern processing, disambiguation, spelling checking or whatever is required.[63]

Taking the analysis a little further, a perspective object can be created. A perspective object can reference the composite object but adds a visual appearance (format) to it. One subclass of a perspective might present a visual in an Excell or Lotus spreadsheet. A different perspective object might produce a printed report appearance And the advantage here is that a database designer could create a number of different composites, a number of different special purpose relations, a number of different perspectives and we now have a whole different methodology of designing databases. Instead of developing database applications from scratch they say "I have a new application and it requires invoices, do I create a new screen form from scratch? No. I have the underlying tables in the database. I pull out composite classes that have header and line items. I might change a few things in its code when I make an instance of it for the specific application. I pull out an existing perspective, I have it." The programmer is not generating new stuff, he is taking old stuff and putting it together in a somewhat new way. An altogether different method of designing, developing, and coding.[64]

Value Based Networks and Visual Interface

During this initial increment, something must be done about direction 2: research and implement value based semantic networks. Design new code and implement them on a small scale. Then, as increment 1 nears finishing, the experience with adaptivity can be utilized and placed on top of a stronger foundation. Flexibility can then be added to permit various kinds of references, metaphors, analogies, and examples.[65]

There's also the issue in the new interface paradigm which requires exploitation of all of man's strengths. An attempt to move human- database communication to be better than even human-human communication, i.e. better than natural language. If the visual aspect can be added, a step will be taken toward that goal. Instead of a textual thesaurus why not have a visual thesaurus of nodes and links. A system for editing, querying and manipulating active thesauri. If you have a number of terms you want to explore you can mouse on all of them, make them active, ask the network to process and if they happen to be incompatible and cause query failure, the system comes back using conceptual pattern processing and shows you what the remaining trade-offs are visually, rather than entering text and reading it. The system is now guiding the user through moving from a state of little knowledge to a state of more knowledge as it should.[66]

The Fourth Database Era - The Era of General Modeling

In increment 2, cross-leveraging and cross-fertilizing can start. The adaptive object-oriented system can be placed on top of the value based semantic network. New features can be added to it: exceptions handling, additional flexibility, and more visuals.

What is the result of direction 1, increment 2, when there is a well developed adaptive layer on a relational database management system? The authors it is a new modeling formalism. SQL and data sublanguages do not spring out of nowhere. A language is not a primary, it's a secondary. The primary is a modeling formalism. Codd created relational tables with rows and columns and as a consequence designed a language. The first languages, the relational calculus and the relational algebra, later evolved into SQL. In a similar manner a modeling formalism is proposed here. Dealing not with specific relations but with composites and perspectives. Our modeling formalism will eventually get extended and bring in the value based semantic formalism. Obviously, visual interface will be a necessary part of the formalism. This new model can also have a command level interface which, with its adaptivity and conceptual orientation, is a significant step beyond a data sublanguage.[67]

Users are no longer dealing with a data sublanguage, they are dealing with something higher: an information sublanguage that is a modeling language designed for higher and/or more appropriate levels of modeling. Whatever method is created for interfacing visually with the database is a sublanguage of its own. It's a visual language for dealing with the database models. This paper has proposed a different methodology based on dealing with object-oriented composites and reusing existing composites to form a value based semantic network. This approach uses special relation objects containing expert systems to provide an adaptive, flexible user interface. A significant advantage of this approach is the reusability of code written in the object-oriented languages. Object-oriented code can easily be modified to create new objects. The more code is developed for reuse and cross leveraged the more that can be accomplished.

This paper has shown some excellent areas for continued research in database management theories. Projecting these areas into the future, the time line of database evolution looks like this:[48]

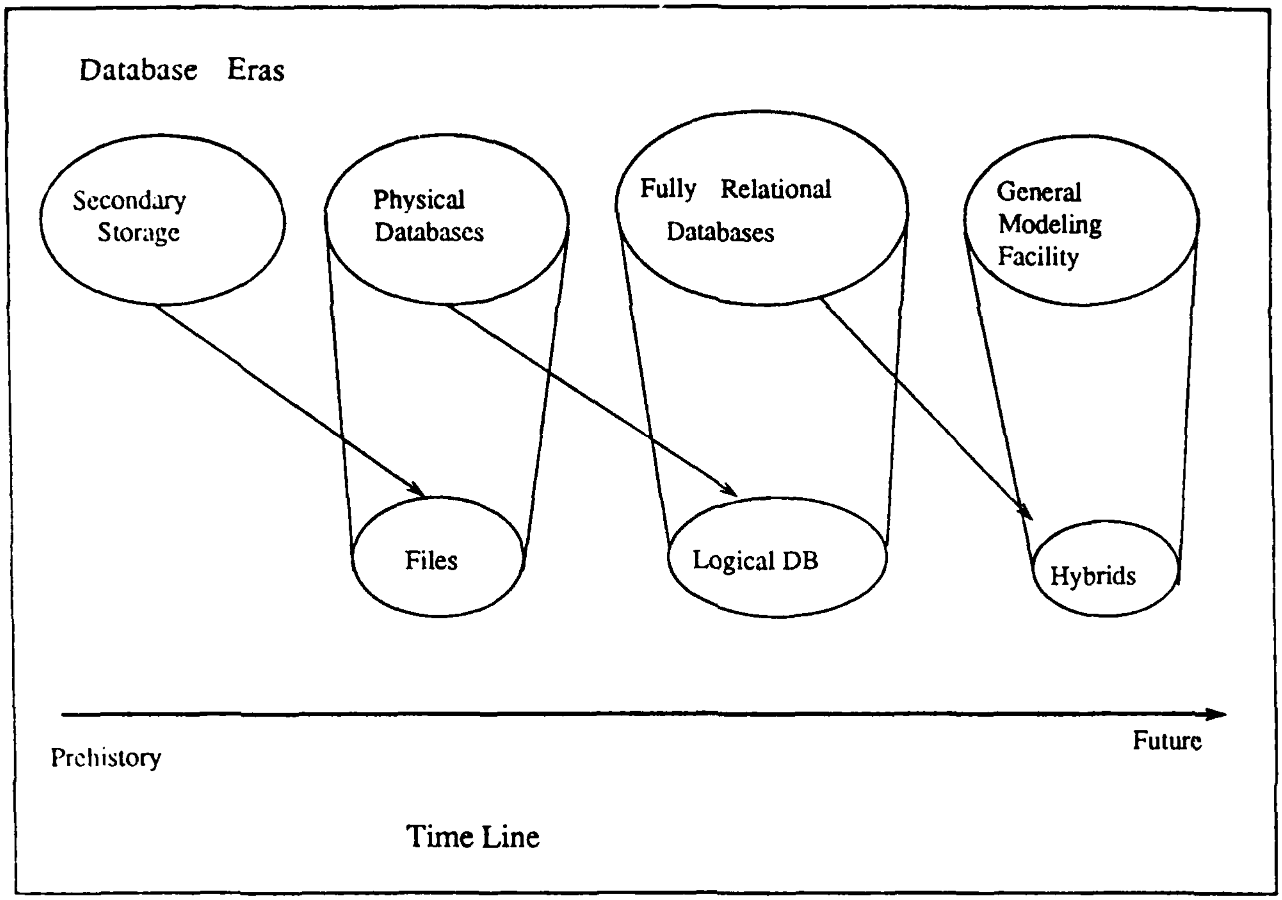

Figure 16 - Projected Database Evolution

10. REFERENCES

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